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Control of Poa annua L. infestations in sports turf with Lolium perenne L. and ethofumesate.

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CONTROL OF *POA ANNUA* L. INFESTATIONS IN SPORTS TURF WITH *LOLIUM PERENNE* L. AND ETHOFUMESATE

A Thesis Presented

By

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CHAPTER I

INTRODUCTION

Poa annua L. (annual bluegrass) is a serious weed problem common in sports turf. Annual bluegrass is at best a biennial. It is subject to various types of stress, making it an undesirable species in the sports turf stand. Various management programs have been developed to control annual bluegrass, but these programs are often unacceptable because they damage the desirable turf.

The purpose of this research is to investigate a management system designed to control annual bluegrass in sports turf while maintaining a playable turf. The objectives are: 1. to investigate the competitive ability of *Lolium perenne* L. (perennial ryegrass) and *Poa pratensis* L. (Kentucky bluegrass) against annual bluegrass, 2. to study the effect ethofumesate has on the growth and development of desirable turfgrass cultivars, and 3. to evaluate the effectiveness of using perennial ryegrass in conjunction with treatments of the herbicide ethofumesate to control annual bluegrass in sports turf.

CHAPTER II

REVIEW OF LITERATURE

Poa annua L.

Poa annua L. (annual bluegrass), also known as annual meadowgrass or wintergrass, is a cool season turfgrass species native to Europe, but is found worldwide (3). Characteristics of annual bluegrass include light green or yellowish green color, bunching growth habit under low maintenance regimes, and intermediate leaf texture (3, 4). In cool and humid climates annual bluegrass behaves as a summer annual (4). Ironically many cultural practices of intensively maintained turf are ideal for the growth of annual bluegrass and seed production. Large numbers of annual bluegrass seeds germinating in sports turf have made annual bluegrass a common problem for sports turf managers. To control the problem many chemical treatments have been tried with limited success.

Annual bluegrass is affected detrimentally by heat and water stress. Investigators (8, 9) have shown that annual bluegrass matures and dies rapidly at temperatures in the range of 30-35^{o}C. It has also been reported to be injured from internal water stress more readily than Kentucky bluegrass or creeping bentgrass species (2, 8). Wehner and Watschke (61) demonstrated that Kentucky bluegrass was more heat tolerant than annual bluegrass under low maintenance regimes, but under intensive maintenance annual bluegrass was as heat tolerant as Kentucky bluegrass.

High intensity cultural practices used on sports turf such as close mowing, high fertilization, and excessive irrigation, foster ideal growing conditions for annual bluegrass (2, 3). A cultural program as such enhances the growth of annual bluegrass, making it an aggressive competitor (2). Height of cut has an effect on the competitive ability of annual bluegrass. Bogart and Beard (6) found that annual bluegrass cut at 1.25, 2.54, 3.75, 5.08, and 6.25 cm yielded the greatest shoot dry weight and largest tiller count when cut at 2.54 cm. Based on these results, the optimum cutting height in terms of shoot competition for annual bluegrass is 2.54 cm. Younger (63) found that close mowing opened areas in the turf enhancing annual bluegrass growth. He also noted that overly wet soils were favorable for persistance of annual bluegrass.

Maintenance regimes influence the seed production of annual bluegrass. If the conditions are optimum, annual bluegrass can be a prolific seed producer (23). Ong (43) showed that severe shortages of nutrients completely inhibited reproductive growth in some plants, but leaves and tillers continued to be produced in a normal pattern. Ong et al (44) found a high nutrient supply during vegetative growth had a strong and lasting effect which was manifested in an increased rate of inflorescence appearance and a greater overall proportion of tillers that flowered. Components of yield most affected by nutrient level were branch numbers, spikelet numbers, and florets per spikelet. The mean weight per seed was mostly unaffected.

The age of annual bluegrass seed and soil temperature affect germination. Cockerham and Whiteworth (9) compared temperatures of 50, 60, and 70°F, and found 60°F was the most favorable temperature for germination. Seeds 4 months old had the highest germination percentage compared to seeds aged 1 and 2 months. Cockerham and Whiteworth also noted the optimum temperature range for annual bluegrass germination in the field was 50-70°C. Oswald and Hagger (45) reported the greatest invasion of annual bluegrass seedlings in 1 year old ryegrass swards was in September, with a second peak in May. They also observed that the greatest numbers of seedlings occurred in the wettest site. Light has been reported to be a requirement for germination of annual bluegrass (4). Infestations will occur when voids in the turf caused by either divots, traffic, disease, or insects are present and if environmental conditions are favorable for annual bluegrass seed germination (4).

Annual bluegrass is often considered a weed in sports turf due to its undesirable qualities, such as low tolerance to heat, water stress, and prolific seed head production, but sports turf maintenance procedures often favor annual bluegrass invasion. Because of undesirable characteristics of annual bluegrass numerous chemical treatments have been applied to control annual bluegrass, but with only limited success.

Post emergence applications of inorganic arsenicals have been used on Kentucky bluegrass and bentgrass turfs to control annual bluegrass infestations (11). These compounds often injured the desirable turf. Turgeon et al.(59) found that repeated applications of calcium arsenate to Kentucky bluegrass caused shallow rooting, thatch development, lower soil water infiltration due to lack of earthworms, higher disease incidence, and higher wilt tendency. Engel et al.(17) noted that the quality of a bentgrass fairway was often reduced by the application of 50% calcium arsenate treatments. It was reported that multiple applications of endothall obtained the best control of annual bluegrass in "Merion" Kentucky bluegrass, but temporary browning of the turf did occur (60). Post-emergence treatments of linuron (33) also controlled annual bluegrass in Kentucky bluegrass turf, but damage to creeping bentgrass, hard fescue, and perennial ryegrass was evident. Pre-emergence treatments of bromocil, benefin, bensulide, DCPA, and triflurolin were shown to effectively control artificially introduced annual bluegrass (21). However, injury to desirable grasses by some of these materials has been reported by investigators (7, 10, 20, 23, 52).

Few chemical treatments have resulted in an acceptable method of controlling annual bluegrass. Because of undesirable qualities, annual bluegrass is still a serious weed problem in sports turf. An alternative approach to annual bluegrass control would be to investigate the effects of plant competition by desirable turf grass cultivars on the growth of annual bluegrass.

Competition

"Competition arises where 2 or more organisms need a common resource whose supply falls below their combined demands."[1] Interactions of many factors affect competition among plants. Among grasses competition arises for space, light, water, and nutrients (15). Factors such as plant densities, species grown in association, and conditions at the time of establishment often influence relative competitive abilities. Tillering of grasses is intimately related to competition between plants and factors that affect competition.

Seed size, monoculture versus mixed culture, planting density, time of establishment, and competition between species sown together have been shown to affect seedling competition. Competition starts when seeds compete for germination sites (15). The faster the seedling establishment rate, the faster a plant can exploit its environment. Investigators (15, 35) found the dominant species had a larger seed which helped it to grow faster, occupy the soil faster, and produce a greater leaf area. Seedling competitive ability has been shown to be advantageous. Rhodes (51) noted that *Lolium perenne* c.v. S-23 (perennial ryegrass) had a greater competitive ability over ryegrass cultivar Ba6280. The competitive

[1] Donald, C.M. 1963. *Advances in Agronomy*. Competition among pasture plants. New York: Academic Press 15: 1-118.

advantage was attributed to S-23's aggressiveness during seedling growth. When these grasses were maintained at a close cutting height, S-23 remained dominant due to its dense tillering habit. Somoliak and Johnston (59) also investigated seedling competition of some grasses grown in monoculture and mixed culture. Monoculture produced larger laminar area, sheath area, total leaf area, leaf length, leaf numbers, and tiller numbers than did mixed cultures. Root length varied in mixed and monocultures. Planting density had an effect on the components of seedling growth too. In greenhouse experiments at sufficiently high densities Rhodes (48) found all components of seedling development such as leaf appearance, leaf length and width, and tiller numbers were detrimentally affected to varying degrees by competitive stress (25). Rhodes (48) also noted that competitive abilities of species vary with plant density. The high or low competitive ability of a species was accentuated with increased densities while maintaining the same species ratio.

Time of establishment also had an effect on competition. King (35) found if _Lolium perenne_ c.v. S-23 (perennial ryegrass) was established before _Festuca rubra_ c.v. S-59 (red fescue) the ryegrass would dominate over the fescue. If the fescue was planted first, it would dominate over the ryegrass, but the advantage the fescue had over the ryegrass would not be as large if the ryegrass was planted first. Hagger (25) studied competition during establishment between _Lolium perenne_ L. (perennial ryegrass) and _Poa trivialis_ L. (rough bluegrass) when sown at the same time. Findings showed that ryegrass tillering per plant was reduced by competitive stress (25). When rough bluegrass was established at the same time as perennial ryegrass the seedlings of ryegrass had a 20-30% reduction in tillering. If rough bluegrass was established before the ryegrass, the reduction in ryegrass tillering was even greater. The ryegrass suffered most from competition during the first 9 weeks of establishement compared to the rough bluegrass. After 9 weeks the growth of the rough bluegrass was reduced more by the ryegrass. Ivens and Mlowe (32) studied competition between seedlings. They tested competition between seedlings of _Ulex europaeus_ L. (gorse) and perennial ryegrass in a replacement series experiment. Their results showed that grown in association with ryegrass, gorse seedlings competed weakly. The ryegrass competed well during establishment due to strong tillering and a strong root system. The rapid shading by the ryegrass was thought to be the main effect of competition.

It appears competition for light often determines which plant will dominate. Hill and Shimamoto (30) showed that the long leaf erect S-24 cultivar of perennial ryegrass was the best competitor of varieties tested because it could intercept the light before the short leaf prostrate varieties. Mixing short leaf and long leaf varieties provided more efficient light utilization, thereby increasing yields. Comparing herbage yields, it was found that ryegrass was the more aggressive species when in competition with annual bluegrass or rough bluegrass (62). A mixed culture of ryegrass and annual bluegrass, or ryegrass and rough bluegrass produced higher yields than a monoculture of either species. This result was due to the bluegrass species exploitation of a different area of the environment than the ryegrass (62). Different areas of the light environment were used by these species because they do not have the same stature and habit. Rhodes (49) showed that a mixture of varieties had a greater yield than varieties grown in monoculture. He found that the highest yielding mixture was that of the erect Ba6280 and the short prostrate S-23 ryegrass because the mixture intercepted the most light.

Competition for light could prove to be detrimental to one of several competing species. In greenhouse studies perennial ryegrass tillering was reduced the most when grown in competition with Rumex obtuifolius (broad leaf dock) compared to Stellaria media L. (chickweed) and rough bluegrass (22). Gibson and Courtney (22) proposed that reduction in tillering was due to a reduction in light intensity by the competing species.

Light exploitation was shown to be related to other factors. McCown and Williams (39) grew Bromus mollis (soft chess) and Erodium botrys (broad leaf filoree) in mixed stands. Generally broad leaf filoree was favored over soft chess, but the former was more aggressive in competition for light. The investigators thought broad leaf filoree competed more aggressively for nutrients. They concluded that the growth of the broad leaf filoree roots was faster than soft chess, but when competition for light was minimal, broad leaf filoree was the aggressor. When the competition for light was greater, soft chess was the more competitive species. King (35) pointed out that the response of one species was greatly conditioned by competition from the other species. For example, the immediate effect of increasing the nutrient level was to favor the dominant species rather than the competing species. The species that can most efficiently procure and utilize the nutrients was not necessarily favored.

Donald (14) pointed out that certain interactions could result when there was competition for one or more factors. In the case of a single factor, perennial ryegrass was the better competitor for nutrients when compared with _Phalaris tuberosa_ L. (harding grass). Ryegrass had the primary effect of reducing the quantity or concentration of nitrogen that harding grass could obtain. The indirect effect was reduction in foliar growth of harding grass because of less nitrogen uptake. The capacity of harding grass to use light was reduced even though the environmental light in the experiment was separate but equal to the one supplied to perennial ryegrass. When harding grass had to compete for light directly with the ryegrass, the direct effect was less photosynthetic activity. The lowered photosynthetic activity resulted in less sugar synthesized, lowered metabolism, greater percentage of nitrogen accumulated in the plant tissue, and a 20% decrease in nitrogen uptake. The capacity of harding grass to use nitrogen was lessened as an indirect effect of light competition. The lowered nitrogen use capacity slowed growth which reduced tillering.

Tillering is a very important process in the growth and development of any stand of grass. Jewiss (34) pointed out tillering of young seedlings greatly aids in the establishment of the stand. He found the main advantage of rapid tillering during establishment was to ensure the production of sufficient leaf area for complete light interception. Tillering was also found to be essential for regeneration of the sward after the removal of the terminal meristem (34). If some plants die in the stand and remaining plants produce more tillers, the longevity of the stand as a unit increased (36).

Tillering rates and tiller densities are determined by an interaction of many variables. A review of the literature by Gardner (19) stated that tillering was related to "organic nutrition, chemical treatment and quality of the seed, soil moisture, mineral nutrition, degree of competition, injury, length of day, temperature, and depth of planting."[2] Gardner (19) showed in his studies that under identical conditions tillering was greater when competition occured between plants of the same species than when 3 different species were involved at the same planting density. Donald (14) found the competitive effect of ryegrass on harding grass tillers was a reduction of both tiller numbers and size.

[2]Gardner, J.L., "Studies in tillering, ecology" 23(2) (1942), p. 164.

Competition for light seemed to reduce only tiller weight while competition for nutrients reduced number and weight. Troughton (58) reported that tillering rates were also related to nutrition. He compared five varieties of perennial ryegrass and found that new tiller production was more sensitive to nitrogen nutrition and temperature than growth of existing tillers. These facts indicated that formation of meristematic tissue was more sensitive to environmental control.

Tillering of grass species has been reported to be strongly related to competition from surrounding plants. Increased plant spacings increases tillering (19). Plants that can develop and tiller rapidly have a competitive advantage over slower tillering plants. Competition also determined the tiller density per unit area. Younger et al. (64) noted that leaf emergence in Kentucky bluegrass progressed at a constant rate until intertiller competition was achieved. Emergence of primary tillers from the main shoot was at a constant rate for each cultivar until interference from competition. Jewiss (34) found that over a period of time the plant numbers decreased once the maximum density in the stand was reached, but the tillers per area remained the same.

It has been documented that a plant species can dominate over another species. Hallgren (29) noted that perennial ryegrass is a good ley competition from establishment because of its great ability to tiller rapidly compared to other forages. McKell et al. (40) studied the competitive relationships of *Lolium multiflorum* L.

(annual ryegrass), Poa pratensis L. (Kentucky bluegrass), Phalaris tuberosa (harding grass), and Blando brome (wild oats) planted in monospecific and bispecific studies in the greenhouse and field. Results showed that annual ryegrass offered great interference to the other species tested. Dry matter yields of wild oats, a weed, were reduced considerably by annual ryegrass. The ryegrass appeared to produce plants of about the same weight whether seeded alone or with other species less aggressive than the ryegrass. Ryegrass was found to compete against itself at high densities. A significant reduction in dry weight per plant was observed when annual ryegrass was grown in both the greenhouse and field, in monospecific culture at seedling rates equal to bispecific culture.

Competitive ability of species grown with other competitive species cannot be generalized. Rhodes (48) pointed out that competitive abilities may be specific in nature. Competitive ability depends on what species are grown in association. It is also dependent on environmental factors such as nutrients and light. Under certain environmental conditions the competitiveness of one species might be greater than the other species, but when conditions change the aggressing role may be reversed. This was shown by McCown and Williams (39) working with soft chess and broad-leaf filoree. Investigation into the competitive relationship of annual bluegrass and turf type perennial ryegrass has not been made. If turf type perennial ryegrass was shown to be more aggressive than annual bluegrass it might possibly be used in controlling annual bluegrass in sports turf.

Even if the ryegrass was an aggressive competitor with the annual bluegrass, it is questionnable whether the ryegrass could compete if the annual bluegrass was already established. King (35) pointed out that a species sown into an existing stand and having good germination would have a long hard time reaching the next stage in development unless dominance of the existing species was slowed. A relatively new herbicide, ethofumesate, has been reported to reduce growth and inhibit germination of annual bluegrass while being safe to use on ryegrass (1, 5, 12, 17, 24, 26, 27, 28, 37, 38). If the turf type perennial ryegrasses are not competitive over annual bluegrass, ethofumesate could possibly supply the competitive advantage for the ryegrasses.

Ethofumesate

Pfeiffer (46) reported that a new herbicide, ethofumesate [(-+)2-ethoxy-2,3-dihydro-3,3-dimethylbenzofuron-5-yl-methylsul phonate], was active primarily against grasses (Gramineae) and sedges (Cyperaceae) of which annual bluegrass was found to be highly susceptible. Some broad leaf weeds were also reported susceptible.

Pfeiffer (46) found the maximum uptake of ethofumesate by susceptible species occurs in emerging shoots of seedlings or into new shoots of mature plants as the shoot passes through treated soil. Since the uptake occured in the aqueous phase, activity in dry soil was greatly reduced. The uptake of the chemical through roots was found to be significant but relatively low compared to shoots. Post-emergence foliage activity was reported to be negligible by Pfeiffer. He did find that growth inhibition by pre-emergence applications to susceptible species could persist for up to 6 months. Pfeiffer (46) also found that wax formation on *Brassica* and *Pisum* foliage was greatly inhibited by ethofumesate, and mitosis in apical meristems of wild oats was inhibited 50-70% without evidence of mitotic aberrations. The selective growth inhibitory effects of ethofumesate have made it useful as an herbicide.

Ethofumesate controlled many annual weeds selectively in sugarbeet fields (16, 47). Engel and Day (17) reported that major weeds could be suppressed with 0.75-1.5 kg/ha applications of ethofumesate while Griffiths and Hammond (24) showed that a rate of 2.0 kg/ha provided excellent control of annual bluegrass. It appears ethofumesate can selectively suppress annual bluegrass in ryegrasses. Hagger and Bastian (26) growing weed grasses in pots showed that ethofumesate was most effective as a pre-emergence herbicide in perennial ryegrass. These investigators found that a 0.6 kg/ha treatment of ethofumesate was a sufficient rate to control annual bluegrass. The study also showed that once the 2-3 leaf growth stage of annual bluegrass was reached, 2.1 kg/ha was needed for control. However, fully tillered annual bluegrass treated with 3.0 kg/ha of ethofumesate exhibited a 80% reduction in yield. Work done by Lee (37) illustrated that ethofumesate applied at rates ranging from 0.8-4.5 kg/ha as pre-emergence treatments, or early post-emergence treatments eliminated annual bluegrass in Italian ryegrass (Lolium multiflorum Lam.). Hagger and Kirkham's (27) results confirmed the other investigators work. They found that ethofumesate was effective in suppressing annual bluegrass in autumn sown perennial ryegrass. Lee (38) demonstrated that early post-emergence treatments at rates of 1.4-4.5 kg/ha controlled all annual bluegrass that survived diuron pre-emergence treatments.

Researchers have applied ethofumesate on several grass species other than ryegrass to control annual bluegrass with success. McLean (41) treated established turf composed of Agrostis ssp. (browntop), Agrostis sp. ("Penncross" bentgrass), and Festuca rubra var. commutata (Chewing's Fescue) with single applications of ethofumesate and found the turf showed tolerance to rates of 1.0 kg/ha. However, rapid nectosis and death of annual bluegrass and tip burning of the turf species made the turf aesthetically unacceptable for 2 months following application at the 1.0 kg/ha rate, McLean (41) reported that 3 sequential applications of ethofumesate at a rate of 0.125 kg/ha per treatment showed a 50% maximum control of annual bluegrass 6 months after the initial treatment, and no damage to the turf was observed. Three sequential treatments of 0.25 kg/ha yielded 87% control of the annual bluegrass 6 months after the initial treatment, again with no adverse effects on the browntop, bentgrass, fescue mixture. Dickens (12) also had success suppressing annual bluegrass with ethofumesate. He obtained in excess of 95%

control of annual bluegrass with single pre-emergence applications of ethofumesate applied at a rate of 2.2 kg/ha to perennial ryegrass overseeded on dormant bermudagrass golf greens. When the rate was reduced to 1.1 kg/ha multiple applications were needed. Engel and Day (17) reported ethofumesate was selective to established Kentucky bluegrass, fescue, and bentgrasses when applied at rates ranging from 0.75-1.5 kg/ha. Unlike Kentucky bluegrass, fescue, and bentgrasses, which must be treated after establishment, ethofumesate can be applied to ryegrasses either before or after establishment.

Ethofumesate was selective in annual and perennial ryegrass crops when applied either as a pre-emergence or post-emergence treatment (17); although, the effect of ethofumesate on established ryegrass was somewhat conflicting. Mature Italian and perennial ryegrass stands grown in the greenhouse were found to be tolerant to rates of 1.1 kg/ha (37). Greater tolerances have been noted. In a review article by Ball and Roberts (1) it was reported that 53 established ryegrass varieties were treated with doses of ethofumesate up to 8.0 kg/ha with no detrilierous effect. Other investigators have noticed treatment effects caused by ethofumesate. Lee (37) reported that in one greenhouse experiment perennial ryegrass stand yields were reduced at rates of 2.2 kg/ha, but in another greenhouse study yields were not reduced at the same rate. Ryegrass plants that survived treatment in stands that were reduced recovered rapidly (37). The vigor of the treated ryegrass plants approached that of untreated plants when observed 6 weeks after treatment (37). In other greenhouse tests perennial ryegrass appeared remarkably resistant to 3.0 kg/ha treatments of ethofumesate (26).

Greenhouse results of ryegrass tolerance to ethofumesate were confirmed in field experiments. In field tests Lee (38) reported ethofumesate applied at rates of 1.4-4.5 kg/ha to established perennial ryegrass seed fields eliminated annual bluegrass without causing adverse effects on perennial ryegrass seed yields. Even though many investigators report negligible effects of ethofumesate on treated ryegrasses, the herbicide has been noted by some investigators to affect growth of the species. For example, ryegrasses treated with ethofumesate have been reported to be darker green in color (1).

Information on tolerable rates of pre-emergence treatments of ethofumesate on ryegrass was also somewhat conflicting. Lee (37) found no treatment effect on germination of Italian ryegrass when treated with ethofumesate at rates of 0.0, 2.2, and 4.5 kg/ha. In contrast, Blair (5) found that pre-emergence doses above 2.2 kg/ha damaged ryegrass stands. Greenhouse studies (1) showed that the greatest tolerance of newly sown ryegrass stands was achieved by surface applications of ethofumesate versus soil incorporation. Rates of 0.5-3.0 kg/ha were reported to be well tolerated by ryegrass species either as pre-emergence, or post-emergence treatments. Hagger and Passman (28) found a need to cover ryegrass seeds before spraying with ethofumesate if planting was carried out at the time of application, or reduction in stands would result. The influence of differences in soil properties could possibly explain inconsistancies in ethofumesate tolerance levels of grasses found by investigators.

Soil properties influenced the behavior of ethofumesate and the effect it has on plants after it is applied. Schweizer (53) found that ethofumesate suppressed sugarbeet growth considerably more on a sandy loam soil versus a loam soil. Rates of 3.4 kg/ha or more reduced yields on the sandy loam soil, but rates of 9.0 kg/ha were needed to reduce yields on the loam soil. Greenhouse studies conducted by Schweizer (54) seemed to indicate that the amount of injury to indicator plants was associated with the percent organic matter present in a soil within a textural series. The more organic matter present, the less damage incurred. In other greenhouse studies conducted by Hagger and Bastian (26) organic matter reduced the efficiency of ethofumesate. Ethofumesate failed to produce any marked depression in yield when rates over the range of 0.5-2.0 kg/ha were applied to annual bluegrass grown in soil with 12% organic matter. Hoogstruten et al. (31) found that 4 times the amount of ethofumesate was needed on an organic soil (9% O.M.) compared to a sandy soil (1% O.M.) to obtain the same amount of growth reduction on test plants.

The life of ethofumesate in the soil affects plant responses. Dissipation rates of ethofumesate are different for loam and sandy loam soils. In 1976 Schweizer (55) reported that ethofumesate dissipates faster in a sandy loam soil (62% sand, 27% silt, 11% clay, 2.2% O.M.) versus a loam soil (41% sand, 45% silt, 14% clay, 1.9% O.M.). Twenty-four weeks after ethofumesate was applied at rates of 2.2, 3.4, 4.5, and 9.0 kg/ha the herbicide was 88-91% dissipated in the sandy loam soil while it was only 72-77% dissipated in the loam soil. The average computed half life in the sandy loam soil was 5.6 weeks compared to 7.7 weeks for the loam soil. Schweizer (55) found that the half lives within each soil type were not significantly different between the treatment rates. The rate of degradation of ethofumesate was independent of the amount applied. Hagger and Passman (28) estimated the half life of a 2.0 kg/ha September application of ethofumesate on a sandy loam to be 2 months; however, after 7 months .42 ppm of ethofumesate remained, which was estimated to be enough to control 50% of the annual bluegrass.

The rate of degredation has been linked by some investigators to soil microbial activity. Hoogstruten et al. (31) reported that ethofumesate degredation was almost entirely due to action of soil microbes. Ethofumesate dissipates faster in warm moist soils in contrast to cold dry soils. After freezing soil for 9 months at -17 degrees C, or sterilizing and storing the soil in a wet and warm environment, Hoagstruten et al. (31) found that ethofumesate residues were not reduced. This data was supported by Schweizer (55) who found ethofumesate applied at 4.5 and 6.7 kg/ha in November dissipated faster in soil that was exposed to high greenhouse temperatures than cold field soil. It was reported that after 140 days in the greenhouse the soil with 4.5 kg/ha treatment reduced the height of corn by 18% while soil from the field (low temperature storage) reduced the height by 53%. Schweizer (55) also found that ethofumesate applied in the field at a rate of 4.5 kg/ha dissipated 2 times faster if treated in March compared to a November treatment. Ten days after the March treatment ethofumesate residues were not detected with a corn bioassay.

Timing of herbicide applications was found to affect soil residues. Schweizer (56) showed that ethofumesate activity was prolonged when it was applied in broadcast applications both pre-plant and post-emergence one month apart compared to a single pre-plant application. Fifteen weeks after the initial pre-plant applications 90-93% of the herbicide had dissipated in the soil where a single pre-plant application was made, whereas only 64-67% of the herbicide had dissipated on the combined pre-plant and post-emergence treatment plots (56).

Movement of ethofumesate soil residues was reported not to be great. Hagger and Passman (28) reported the movement of ethofumesate to be primarily in the upper 2 cm of soil. Hoogstruten et al. (31) reported ethofumesate does not leach beyond 5-20 cm in most agricultural soils. Schweizer (55) also found little movement in soils. He reported that independent of rates the herbicide was found mainly in the upper 7.5 cm in sandy loam and loam soils. Less than 50% of the ethofumesate reached the 7.5-15 centimeter depth. Slightly more leaching to the 7.5-15 centimeter depth was noted in the sandy loam soil when compared to the loam soil.

CHAPTER III

COMPETITION EXPERIMENTS

Experiment 1

Materials and methods. Experiment 1 was designed to test the competitive ability of one tiller of either *Lolium perenne* L. (perennial ryegrass) or *Poa pratensis* L. (Kentucky bluegrass) against the competitive ability of four tillers of *Poa annua* L. (annual bluegrass).

Growing containers used were 473.2 ml polystyrene plastic cups with 4, 0.45 cm diameter holes punched in the bottom of the cups to provide drainage. These were filled with an unsterilized 5:3 (v:v) mixture of sand and peat. Sods obtained from mature grass stands grown in Hadley silt loam soil (Typic Udifluvent) on the University of Massachusetts South Deerfield Turfgrass Research Station were separated into individual tillers and selected for uniform shoot and root system size. Five plants or individual tillers were planted per cup. Four annual bluegrass plants were planted 3.5 cm from each other around the perimeter of the cup. One of each turfgrass tested was planted in the center of the cup, 2.5 cm from each of the four surrounding plants. A template was used to insure uniform plant spacing (Figure 32). Nine turf type perennial ryegrass cultivars, 4 Kentucky bluegrass cultivars, and annual bluegrass were tested (Table 1). Each of the 14 turfgrasses tested were replicated

TABLE 1

TURFGRASSES TESTED IN COMPETITION EXPERIMENTS 1 & 2

A. *Lolium perenne* L. Cultivars:

1. Citation
2. Elka
3. Diplomat
4. Loretta
5. Manhattan
6. Norlea
7. Pelo
8. Pennfine
9. Yorktown II

B. *Poa pratensis* L. Cultivars:

1. A-34
2. Brunswick
3. Touchdown
4. Ram I

C. Weedgrass

1. Annual bluegrass (*Poa annua* L.)

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8 times. Cups were placed in a completely randomized design in a plastic greenhouse and were rerandomized weekly to minimize edge effects of the benches on the plants.

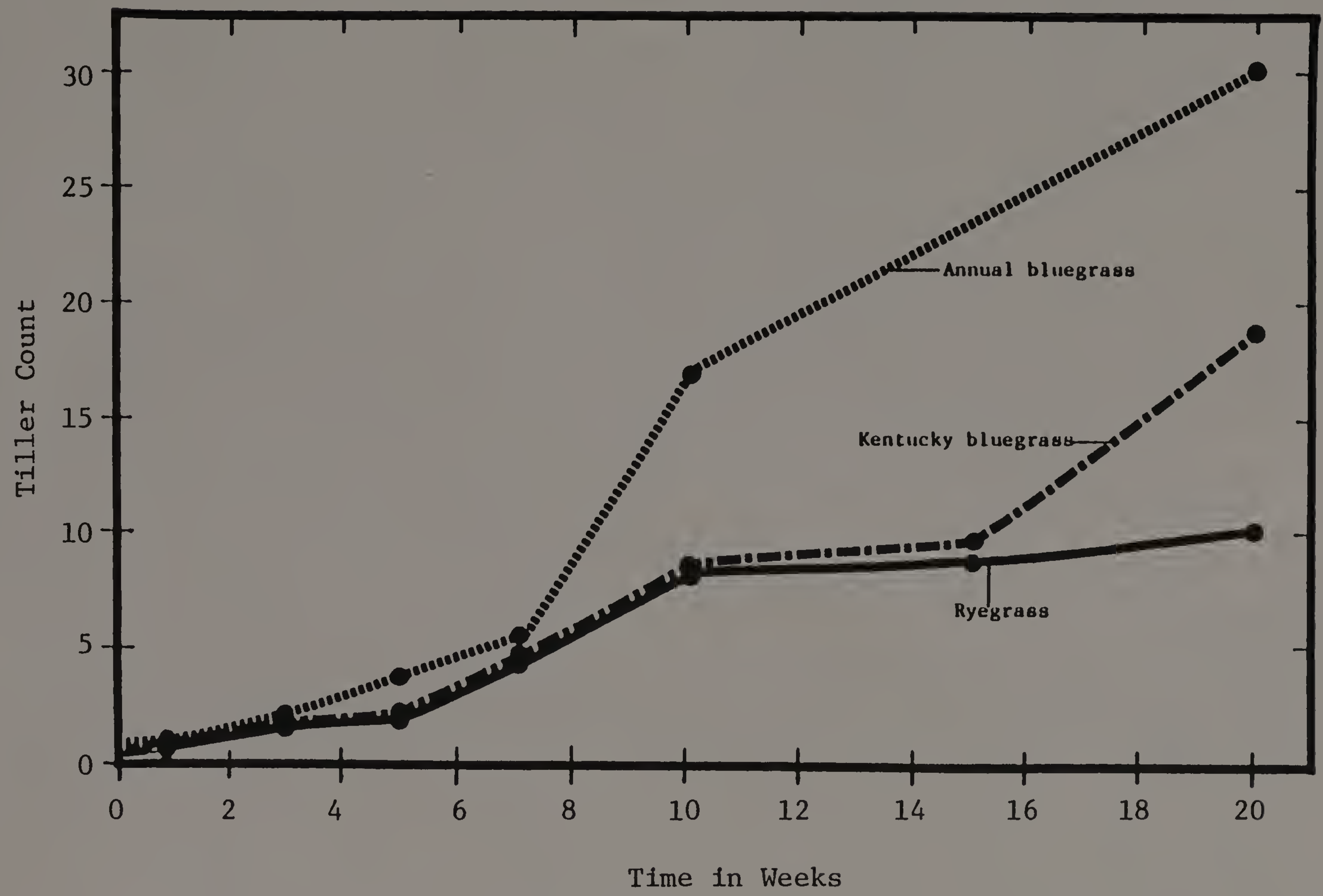
Plants were watered 2-3 times a week. Nutrients were provided by weekly applications of half strength Hoagland's solution. Turfgrass plants were cut every 2-3 days at a height of 1.9 cm. Fungicide and insecticide treatments were made occasionally as needed. Sulfur lamps and direct applications of sulfur were used to control powdery mildew (*Erysiphe graminis* D.C.) on Kentucky bluegrass cultivars.

Tiller counts of the center plant were made on weeks 1, 3, 5, 7, 10, and 15, and recorded. Data collected at week 20 included tiller counts of the center plant and 4 surrounding plants. Shoots of the plants were then cut at the growing media, air interface and placed in a forced air drying oven maintained at 70^{o}C and then weighed. The significance of the turfgrass treatments was determined by Duncan's Multiple Range test.

Results. Mean tiller counts graphed over time for the turfgrasses grown in the center of four annual bluegrass plants are illustrated in Figure 1. Tillering rates of the perennial ryegrass cultivars generally followed the same pattern within the species. The same was true for Kentucky bluegrass cultivars. Since there was little difference within the species, perennial ryegrasses were graphed as one group and Kentucky bluegrasses were graphed as another group.

The turf type perennial ryegrasses, and Kentucky bluegrasses tillered at about the same rate through week 15 (Figure 1). Both species had a steady tillering rate of over 1 tiller per week between weeks 5 and 10. Between weeks 10 and 15 tillering slowed to less than one quarter of a tiller per week for both species. Tillering of Kentucky bluegrasses increased to over 2 tillers per week between weeks 15 and 20, while the tillering rate of ryegrass did not increase. Annual bluegrass tillered at a faster rate after week 3 than either the Kentucky bluegrasses or the turf type perennial

Fig. 1. Tiller Counts Over Time of Center Plants of Ryegrass, Kentucky Bluegrass, and Annual Bluegrass in Experiment 1.



ryegrasses. Between weeks 7 and 10 annual bluegrass tillering was at a rate of over 5 tillers per week. The tillering rate of annual bluegrass slowed to a rate of less than 1.5 tillers per week between weeks 10 and 20.

Final tiller counts of the turfgrasses tested in the center of the cup were compared at week 20. Annual bluegrass grown in the center surrounded by 4 annual bluegrass plants had the largest mean tiller count of all the center grown grasses with 30.1 tillers (Table 2). Tillering of annual bluegrass was significantly greater than all ryegrasses tested. Annual bluegrass tillering was also significantly greater than Touchdown and Ram I Kentucky bluegrasses, but not significantly greater than A-34 or Brunswick Kentucky bluegrasses. Elka perennial ryegrass had the largest mean tiller number of the perennial ryegrasses tested (Table 2). Although Elka produced the largest number of tillers, it was only significantly greater than the poorest tillering ryegrass, Pennfine. Among the ryegrass cultivars tested, Elka, Manhattan, and Pelo had the largest mean tiller counts with 16.0, 15.0, and 12.8 tillers respectively. Citation, Norlea, and Pennfine were the poorest tillering perennial ryegrasses with counts of 6.9, 6.3, and 5.6. Bluegrasses A-34, Brunswick, and Touchdown tillered more than all the ryegrasses with 21.0, 20.5, and 19.5 tillers per plant respectively. These Kentucky bluegrasses tillered significantly greater than half the ryegrasses tested. Ram I Kentucky bluegrass had 14.4 mean tillers per plant, but it did not tiller significantly greater than any of the

TABLE 2

TURFGRASSES, TILLER COUNT AND SHOOT DRY WEIGHT OF CENTER TURFGRASS PLANT, TILLER COUNT AND SHOOT DRY WEIGHT OF 4 SURROUNDING ANNUAL BLUEGRASS PLANTS, COMPETITION EXPERIMENT 1

Turfgrasses	Mean Tiller Count Center Turfgrass Plant	Mean Shoot Dry Weight Center Turfgrass Plant	Mean Tiller Count 4 Surrounding Annual Bluegrass Plants	Mean Shoot Dry Weight 4 Surrounding Annual Bluegrass Plants
Citation	6.9ab*	0.05a	165.0	1.05d
Elka	16.9bcde	0.10abcd	155.9	0.96bcd
Diplomat	8.8abc	0.08abc	160.6	0.97bcd
Loretta	9.9abcd	0.08abc	165.8	1.03d
Manhattan	15.0abcde	0.14bcd	153.0	0.84bc
Norlea	6.3ab	0.06a	159.5	0.97bcd
Pelo	12.8abcde	0.13abcd	156.9	0.83bc
Pennfine	5.6a	0.07ab	185.5	1.01cd
Yorktown II	7.6ab	0.08abc	167.1	1.04d
A-34	21.0ef	0.16cd	174.4	0.87bcd
Brunswick	20.5def	0.15bcd	172.6	0.95bcd
Touchdown	19.5cde	0.13abcd	173.0	0.88bcd
Ram I	14.4abcde	0.09abc	158.5	0.80b
Annual Bluegrass	30.1f	0.18d	123.8 $p = 0.12$	0.64a

*Values within columns followed by same letter are not significantly different at the 5% level.

ryegrasses.

Annual bluegrass had the largest shoot dry weight, 0.18 g, but it was not significantly greater than A-34 (0.16 g), Brunswick (0.15 g), and Touchdown (0.13 g), Kentucky bluegrasses; or Elka (0.10 g) Manhattan (0.14 g), and Pelo (0.13 g), perennial ryegrasses (Table 2).

There were no significant differences (p = 0.12) in tiller counts of the 4 surrounding annual bluegrass plants, but 4 annual bluegrass plants that surrounded itself had the smallest tiller count, 123.8. Annual bluegrass surrounding the poorest tillering ryegrass, Pennfine, had the largest number of tillers, 185.5.

Shoot dry weights of the 4 annual bluegrass plants showed significant variation (Table 2). The dry weight for the 4 annual bluegrass plants surrounding itself was 0.64 g. It was significantly less than all the other grasses tested. Four annual bluegrasses that surrounded turfgrasses Ram I, Pelo, Manhattan, A-34 and Touchdown had dry weights of 0.80 g, 0.83 g, 0.84 g, and 0.88 g. Annual bluegrass that encircled Yorktown II and Citation had shoot dry weights of 1.04 g and 1.05 g respectively.

Experiment 2

Materials and methods. Experiment 2 was designed to test the competitive ability of 1 tiller of *Poa annua* L. against the competitive ability of 4 tillers of desirable cultivars of either *Lolium perenne*

L. or <u>Poa pratensis</u> L. The same turfgrasses tested in Experiment 1 were tested in Experiment 2 (Table 1). Experiment 2 was the converse in design from Experiment 1 in terms of the planting pattern for each treatment. In this study one annual bluegrass tiller was planted in the center surrounded by 4 tillers of the turfgrasses being tested. The study was carried out concurrently with Experiment 1. All planting, cultural practices, and data collection was done at the same time. The only difference between the two studies was that tiller counts of the center plants were not made at week 15 because the annual bluegrass plants were too large to count accurately without taking apart the study.

<u>Results</u>. Tiller counts of the center annual bluegrass plants were recorded over time at weeks 1, 3, 7, 10, and 20. Since there were not any prominent differences in tillering rates over time only results at week 20 were presented.

Annual bluegrass growing surrounded by itself had the smallest mean tiller number, 30.1 at week 20 (Table 3). Annual bluegrass encircled by the other turfgrasses had larger tiller counts in all cases, but many of the center annual bluegrass plants were not significantly different from annual bluegrass surrounded by itself. Annual bluegrass grown in the center of Elka and Yorktown II perennial ryegrasses had mean tiller counts of 46.8 and 60.5. Annual bluegrass grown surrounded by A-34, Ram I, and Touchdown Kentucky bluegrasses had 54.5, 57.8, and 63.8 tillers respectively. Annual

TABLE 3

TURFGRASSES, TILLER COUNT AND SHOOT DRY WEIGHT OF CENTRAL ANNUAL BLUEGRASS PLANT, TILLER COUNT AND SHOOT DRY WEIGHT OF 4 SURROUNDING TURFGRASS PLANTS, COMPETITION EXPERIMENT 2

Turfgrasses	Mean Tiller Count Center Annual Bluegrass Plant	Mean Shoot Dry Weight Center Annual Bluegrass Plant	Mean Tiller Count 4 Surrounding Turfgrass Plants	Mean Shoot Dry Weight 4 Surrounding Turfgrass Plants
Citation	68.6abcd*	0.48bc	45.8ab	0.48abcd
Elka	46.8ab	0.32ab	123.5f	0.68d
Diplomat	92.6cd	0.45bc	57.9bcd	0.53abcd
Loretta	77.6bcd	0.42abc	62.9bcd	0.44abcd
Manhattan	70.0abcd	0.42abc	79.5de	0.58bcd
Norlea	67.4abcd	0.40abc	26.6a	0.41abc
Pelo	89.3bcd	0.46bc	57.4bcd	0.53abcd
Pennfine	70.6abcd	0.40abc	51.9abc	0.55abcd
Yorktown II	60.5abc	0.36abc	79.6de	0.65cd
A-34	54.5abc	0.40abc	89.9e	0.55abcd
Brunswick	109.6d	0.59c	42.6ab	0.31a
Touchdown	63.8abc	0.30ab	93.6e	0.65cd
Ram I	57.8abc	0.42abc	73.1cde	0.39ab
Annual bluegrass	30.1a	0.18a	123.8f	0.64bcd

*Values within columns followed by same letter are not significantly different at the 5% level.

bluegrass grown in the center of Brunswick Kentucky bluegrass, and Diplomat perennial ryegrass had 109.6, and 92.6 mean tillers.

The mean dry weight of the center annual bluegrass surrounded itself was significantly less than the dry weights of annual bluegrass encircled by Diplomat (0.54g), and Brunswick (0.59g) (Table 3). Annual bluegrass surrounded by itself had a mean shoot dry weight of 0.18 g, followed by 0.30 g, 0.32 g, and 0.36 g for annual bluegrass surrounded by Touchdown, Elka, and Yorktown II.

Mean tiller counts of the 4 grass plants that surrounded the center annual bluegrass ranged from 26.6 for Norlea to 123.8 for annual bluegrass (Table 3). Annual bluegrass and Elka had the highest mean tiller counts for the four surrounding plants with 123.8 and 123.5 respectively. These values were significantly greater from all other turfgrasses tested. Elka perennial ryegrass had the largest shoot dry weight, 0.68 g. Four plants of Yorktown II and Touchdown had mean shoot dry weights of 0.65 g followed by annual bluegrass with 0.64 g, and Manhattan with 0.58 g. These grass weights were all significantly greater than Brunswick which had the lowest mean shoot dry weight for 4 plants, 0.31 g.

Experiment 3

Materials and methods. Experiment 3 was designed to test the competitive ability of either 1 seedling *Lolium perenne* L. or *Poa pratensis* L. against the competitive ability of 4 *Poa annua* L.

tillers. Eight perennial ryegrass cultivars, 4 Kentucky bluegrass cultivars, and annual bluegrass were tested (Table 4). In this

TABLE 4

TURFGRASS CULTIVARS TESTED IN COMPETITION EXPERIMENTS 3 AND 4

A. *Lolium perenne* L. Cultivars:

1. Citation
2. Diplomat
3. Elka
4. Loretta
5. Manhattan
6. Pelo
7. Pennfine
8. Yorktown II

B. *Poa pratensis* L. Cultivars:

1. A-34
2. Adelphi
3. Touchdown
4. Majestic

C. Weedgrass

1. Annual bluegrass (*Poa annua* L.)

study 1 seedling of the cultivar tested was planted in the center of the cup surrounded by 4 annual bluegrass tillers.

Seeds used were germinated on number 4 filter paper in petri dishes saturated with half strength Hoagland's solution. The petri dishes were placed in a growth chamber maintained at 24°C with 10 hours light. Eight days after placement in the growth chamber seedlings of the turf type perennial ryegrasses and seedlings of annual bluegrass were selected visually for uniform size and vigor. Seedlings were planted in cups as in Experiment 1. Sixteen days after placement in the growth chamber, the seedlings of the Kentucky bluegrass cultivars were visually selected for uniformity and planted. Cultural maintenance of the study was similar to Experiment 1. The experiment was terminated 20 weeks from the time of initiation in the growth chamber. Data collected at termination included tiller counts and shoot dry weights of the center plants and 4 surrounding plants. Dry weight analysis was carried out as in Experiment 1. Significance of the turfgrass treatments was determined by Duncan's Multiple Range Test.

Results. One seedling annual bluegrass grown against 4 tillers of annual bluegrass had significantly the largest mean tiller count, 56.6 tillers (Table 5). Seedlings of Elka, Manhattan, and Pennfine perennial ryegrass had the next largest mean tiller counts, 38.6, 23.9, and 23.4 when grown against 4 annual bluegrass tillers. Kentucky bluegrasses Majestic and Adelphi had the largest mean tiller counts with values of 19.0 and 18.6. The poorest tillering cultivars were Loretta and Diplomat perennial ryegrasses along with Touchdown Kentucky bluegrass. These grasses had mean tiller counts of 9.8, 13.3 and 10.6 respectively.

The center plant of annual bluegrass surrounded by 4 annual bluegrass plants had a mean shoot dry weight of 0.35 g which was not significantly different from the mean shoot dry weights of Manhattan, Elka, or Pennfine (Table 5). The dry weights of these

TABLE 5

TURFGRASSES, TILLER COUNT AND SHOOT DRY WEIGHT CENTER TURFGRASS PLANT, TILLER COUNT AND SHOOT DRY WEIGHT 4 SURROUNDING ANNUAL BLUEGRASS PLANTS, COMPETITION EXPERIMENT 3.

Turfgrasses	Mean Tiller Count Center Turfgrass Plant	Mean Shoot Dry Weight Center Turfgrass Plant	Mean Tiller Count 4 Surrounding Annual Bluegrass Plants	Mean Shoot Dry Weight 4 Surrounding Annual Bluegrass Plants
Citation	16.4a*	0.13ab	224.0	1.07
Diplomat	13.3a	0.09ab	227.9	1.09
Elka	38.6b	0.23abc	190.8	1.04
Loretta	9.8a	0.06ab	233.0	1.10
Manhattan	23.9ab	0.26bc	192.8	1.11
Peol	17.5a	0.13ab	202.0	1.26
Pennfine	23.4ab	0.19abc	234.5	1.17
Yorktown II	18.9ab	0.10ab	246.8	1.25
A-34	11.5a	0.07ab	208.3	1.08
Adelphi	18.6ab	0.13ab	209.0	1.20
Touchdown	10.6a	0.06ab	204.5	1.27
Majestic	19.0ab	0.14ab	240.9	1.10
Annual Bluegrass	56.6c	0.35c	223.1	1.16
			P = 0.12	P = 0.76

*Values within columns followed by same letter are not significantly different at the 5% level.

ryegrasses were 0.26 g, 0.23 g, and 0.19 g respectively. The shoot dry weight of Majestic and Adelphi Kentucky bluegrass were 0.14 g and 0.13 g. Loretta and Touchdown both had a dry weight of 0.06 g.

Significant differences were not evident ($p = 0.12$) between the tiller counts of the 4 surrounding annual bluegrass plants (Table 5). Similarly there were no significant differences ($p = 0.76$) between the mean shoot dry weights of the 4 surrounding annual bluegrass plants that surrounded the center turfgrasses (Table 5).

Experiment 4

Materials and methods. Experiment 4 was designed to test the competitive ability of 1 *Poa annua* L. tiller against the competitive ability of either 4 *Lolium perenne* L. seedlings or 4 *Poa pratensis* L. seedlings. The same grasses tested in Experiment 3 were tested in Experiment 4 (Table 4). Experiment 4 was the converse in design of Experiment 3 in terms of the planting pattern for each treatment. In this study 1 tiller annual bluegrass was planted in the center of the cup surrounded by 4 seedlings of the turfgrass cultivar being tested. Planting, maintenance, data collection, and data analysis was carried out in the same manner and at the same time as in Experiment 3.

Results. One annual bluegrass tiller grown against 4 seedlings of annual bluegrass had the lowest mean tiller number, 18.5, at termination of the study (Table 6). Although not significancly

TABLE 6

TURFGRASSES, TILLER COUNT AND SHOOT DRY WEIGHT OF CENTER ANNUAL BLUEGRASS PLANT, TILLER COUNT AND SHOOT DRY WEIGHT OF 4 SURROUNDING TURFGRASS PLANTS, COMPETITION EXPERIMENT 4

Turfgrasses	Mean Tiller Count Center Annual Blue-grass Plant	Mean Shoot Dry Weight Center Annual Bluegrass Plant	Mean Tiller Count 4 Surrounding Turfgrass Plants	Mean Shoot Dry Weight 4 Surround-ing Turf-grass Plants
Citation	23.1ab*	0.11ab	103.1bc	1.05d
Diplomat	85.1cde	0.46bcd	74.0ab	0.62ab
Elka	68.3abcd	0.43abcd	172.3d	0.95cd
Loretta	88.4de	0.46bcd	92.5abc	0.58ab
Manhattan	33.8abc	0.16abc	91.1abc	0.99d
Pelo	57.5abcd	0.35abcd	85.1abc	0.84bcd
Pennfine	42.5abcd	0.21abc	99.3abc	0.81bcd
Yorktown II	72.4bcde	0.49cd	101.5bc	0.87bcd
A-34	93.0de	0.61de	99.0abc	0.64abc
Adelphi	75.8bcde	0.49cd	81.3abc	0.67bc
Touchdown	61.8abcd	0.40abcd	116.3c	0.77bcd
Majestic	122.9e	0.84e	61.0a	0.36a
Annual Bluegrass	18.5a	0.11a	238.1e	1.37e

*Values within columns followed by same letter are not significantly different at the 5% level.

different from annual bluegrass grown against itself, one annual bluegrass tiller grown against Citation, Manhattan, and Pennfine seedlings had mean tiller counts of 23.1, 33.8, and 42.5 respectively. Tiller counts of annual bluegrass grown against Loretta, Diplomat, and Yorktown II perennial ryegrass had values of 88.4, 85.1, and 72.4. These values were significantly different from annual bluegrass grown against itself. Annual bluegrass surrounded by Touchdown had a tiller count of 61.8, significantly less than the other Kentucky bluegrass cultivars tested.

Annual bluegrass grown in the center of both 4 Citation plants and 4 annual bluegrass plants had mean shoot dry weights of 0.11 g (Table 6). Annual bluegrass surrounded by 4 plants of either Manhattan, Pennfine, and Touchdown had mean shoot dry weights of 0.16 g, 0.21 g, and 0.40 g respectively. Annual bluegrass grown in the center of either 4 Yorktown II, Diplomat, or Loretta plants had mean shoot dry weights of 0.49 g, 0.46 g, and 0.46 g.

Mean tiller count of the 4 annual bluegrass seedling plants that surrounded a single annual bluegrass plant were significantly greater than all the other grasses with a count of 238.1 tillers (Table 6). Four Elka seedling plants that encircled annual bluegrass had the next highest count, 172.3 tillers, also significantly different from all other surrounding turfgrasses. Touchdown Kentucky bluegrass surrounding annual bluegrass had a tiller count of 116.3 while Citation and Yorktown II perennial ryegrasses encircling annual bluegrass had 103.1 and 101.5 tillers respectively.

Mean shoot dry weights of annual bluegrass plants surrounding itself had significantly the greatest yield with a dry weight of 1.37 g. Four surrounding plants of Citation had a mean shoot dry weight yield of 1.05 g followed by Manhattan and Elka with yields of 0.99 g and 0.95 g. Touchdown was the highest yielding Kentucky bluegrass with a mean shoot dry weight of 0.77 g for the 4 surrounding plants.

Discussion

The purpose of these studies was to investigate the competitive abilities of selected *Lolium perenne* L. cultivars and selected *Poa pratensis* L. cultivars against *Poa annua* L. Experiments 1 and 2 tested tillers of the turfgrasses grown against tillers of annual bluegrass. Experiments 3 and 4 tested seedlings of the grasses against tillers of annual bluegrass. Recorded data shows the effect of competition on the growth of the grasses.

Tiller counts over time in Experiment 1 differed for annual bluegrass, Kentucky bluegrasses, and perennial ryegrasses (Figure 1). After week 10 tillering rates of the ryegrasses were greatly slowed. Week 10 could possibly be the time at which competition from the annual bluegrass started to affect the growth rate of the ryegrasses. This explanation agrees with Younger et al. (64) who noted that emergence of primary tillers from the main shoot was at a constant rate until interference from competition.

Kentucky bluegrasses followed the same pattern in tillering as perennial ryegrass through week 15. Between weeks 10 and 15 tillering of these 2 species was greatly slowed over the previous 5 weeks. After week 15 tillering rates of the Kentucky bluegrasses was greatly increased. The increased tillering rate was attributed to the tillering of emerged rhizomes. It was conjectured that the reduced rate in Kentucky bluegrass tillering during the weeks prior to week 15 was due to either rhizome initiation and growth, or competitive pressure exerted by annual bluegrass, or both.

After establishment, annual bluegrass tillered at a rate greater than both perennial ryegrasses and Kentucky bluegrasses. Between weeks 7 and 10 annual bluegrass showed a dramatic increase in tillering. During this period the annual bluegrass tillering rate was over 5 times greater than the other species. These results imply that annual bluegrass had a more aggressive growth rate than the other grasses tested.

Comparing tiller counts at week 20 in Experiment 1, annual bluegrass had the greatest number of tillers of the species tested (Table 2). Annual bluegrass was followed by Kentucky bluegrass cultivars and then perennial ryegrass cultivars in tiller numbers when grown against annual bluegrass. These results indicate that annual bluegrass was the most competitive species tested. It has been noted that the plant which can develop and tiller rapidly has a competitive advantage over slower tillering plants (19, 29, 40).

Although annual bluegrass tillered more than all of the turfgrass cultivars tested, there were differences between species and cultivars. Kentucky bluegrass cultivars tillered more than the ryegrasses tested in Experiment 1. The increased tillering of Kentucky bluegrasses was attributed to tillering of emerged rhizomes. There were not many differences in tiller counts between the Kentucky bluegrass cultivars A-34, Brunswick, and Touchdown. They all had mean tiller counts of about 20. Ram I in contrast had 14 mean tillers. Differences in tiller counts existed within the ryegrasses. Elka, Manhattan, and Pelo had 16.9, 15.0 and 12.8 tillers respectively while the poorest tillering ryegrass, Pennfine, had 5.6 mean tillers. It is conjectured if this experiment was continued for a longer period of time the disparity of tiller numbers between the Kentucky bluegrasses and ryegrasses would increase because of tillering of emerged Kentucky bluegrass rhizomes.

Trends in tiller production were generally reflected in dry matter production of the shoots in Experiment 1 (Table 2). Slower tillering grasses had less dry matter. Annual bluegrass had the largest shoot dry weight, but is was not significantly greater than the top 3 tillering bluegrasses or ryegrasses mentioned above.

The increased competitive ability of the faster tillering turfgrasses was noted in the tiller counts and shoot dry weights of the 4 surrounding annual bluegrass plants. Four annual bluegrass plants surrounding itself had significantly less tillers than annual bluegrass plants encircling some of the ryegrasses and most of the bluegrasses. Conversely, 4 annual bluegrasses surrounding the poorest tillering ryegrass had the greatest number of tillers. The mean shoot dry weights followed the same trends.

Experiment 2, the converse in planting pattern of Experiment 1, showed that annual bluegrass competing against itself had the lowest tiller counts. It appears annual bluegrass provided more competitive interference than the tested cultivars of Kentucky bluegrass or perennial ryegrass. This data supports the results of Experiment 1 which suggest annual bluegrass was a more successful competitor. Excluding annual bluegrass and comparing the turfgrass cultivars tested, Elka perennial ryegrass offered the most interference to tillering of annual bluegrass, limiting the count to 46.8. A-34 and Ram I were the best competing Kentucky bluegrasses allowing only 54.5 and 57.8 mean tillers on the center annual bluegrass plant (Table 3). Mean shoot dry weights followed the same trends as tiller counts. Center grown annual bluegrass plants surrounded by grasses that exhibited a reduction in tillering had relatively small shoot dry weights (Table 3).

Four surrounding plants of the turfgrass cultivars which had the largest tiller counts reduced tillering of annual bluegrass the most, again indicating plants that can tiller the fastest have the competitive advantage. Mean shoot dry weights of the 4 surrounding turfgrass plants generally varied with tiller counts. The greater the tiller count, the larger the shoot dry weight.

Results of Experiments 1 and 2 were related. A-34 was the greatest tillering Kentucky bluegrass in Experiment 1. It also offered the most interference to growth of annual bluegrass limiting tillering to a mean 54.5 tillers per replication in Experiment 2. Elka perennial ryegrass tillered the greatest of the ryegrasses grown in Experiment 1. In Experiment 2 Elka limited annual bluegrass tillering to 46.8 mean tillers. Other grasses tested did not correlate between Experiments 1 and 2. Brunswick Kentucky bluegrass grown in Experiment 1 had 20.5 mean tillers when surrounded by 4 annual bluegrass plants. This value was only slightly less than the greatest tillering bluegrass, A-34. Results of Experiment 2 showed that Brunswick offered the least resistance to annual bluegrass, limiting annual bluegrass to 109.6 tillers, in contrast to 54.5 tillers for annual bluegrass surrounded by A-34.

Pennfine, Norlea, Citation, and Yorktown II perennial ryegrasses demonstrated the opposite effect of Brunswick Kentucky bluegrass. These ryegrass cultivars tillered poorly in Experiment 1. Mean tiller counts ranged from 5.6-7.6 when grown against 4 annual bluegrass plants. When annual bluegrass was grown against 4 ryegrass plants of the cultivars previously mentioned, tillering was limited to 60.5-70.6 mean tillers per plant.

The mean tiller counts of 4 plants that surrounded annual bluegrass in Experiment 2 resulted in some interesting trends. Annual bluegrass, Elka, and A-34 limited annual bluegrass tillering to 30.1, 46.8, and 54.5 mean tillers per plant respectively. The mean tiller counts of the 4 surrounding plants of annual bluegrass, Elka, and A-34 were 123.8, 123.5, and 89.9 respectively. It is conjectured that the relatively fast growth of these turfgrasses limited the growth of the center annual bluegrass. The mode of competition could have been exploitation of light. It is possible the 4 outside plants occupied the niche before the center annual bluegrass plant. Results of competition for light limiting growth have been well documented (15, 22, 30, 32, 35, 39, 62).

Other cultivars tested also limited annual bluegrass tillering fairly well, but they did not tiller much themselves. The perennial ryegrass cultivars Norlea and Citation limited annual bluegrass tillering to 67.4 and 68.6 mean tillers per plant. Mean tiller counts of the 4 surrounding plants of these cultivars were 26.6 for Norlea and 45.8 for Citation. Four plants of Brunswick, in contrast, had a mean tiller count of 42.6. Brunswick exerted the poorest competitive pressure on annual bluegrass limiting tillering to an average 109.6 tillers per plant. What made Norlea and Citation such good competitors? Competition for light exerted on the annual bluegrass was probably minimal because of the relatively small canopy size of the Norlea and Citation plants. Competition for nutrients could be an explanation if root growth was faster and greater for the ryegrass, but this explanation is unlikely because of the small size of the ryegrass plants. Weekly applications of nutrients also make the possibility of nutrient deficiencies highly unlikely in these experiments. One possible explanation of the competitive effects of Norlea and Citation on the annual bluegrass is an alleopathic relationship. The ryegrasses could have produced a toxin or toxins that limited the growth of annual bluegrass. To substantiate the explanation extensive investigations would have to be undertaken.

Experiments 1 and 2 tested turfgrass tillers against annual bluegrass tillers. Experiments 3 and 4 tested seedlings of the grasses tested against tillers of annual bluegrass.

Compared with the seedlings of the turfgrasses tested, seedlings of annual bluegrass tillered the greatest when grown in the center of 4 tillers of annual bluegrass in Experiment 3 (Table 5). Seedlings of ryegrasses such as Elka, Manhattan, and Pennfine had tillered more by week 20 than seedlings of Kentucky bluegrass. This result is not surprising as perennial ryegrasses are generally known for quick germination and establishment, and rapid tillering (3). These qualities could have given the ryegrasses a head start in growth. None of the ryegrasses tillered any greater than the Kentucky bluegrasses when vegetative propogules were tested in Experiment 1. When seedlings were tested, some ryegrasses tillered more than the bluegrasses. However, many of the ryegrass cultivars did not tiller any more than the Kentucky bluegrass cultivars when grown against annual bluegrass. Once established it seemed Kentucky bluegrass competed as well as the ryegrasses with annual bluegrass.

A wide range of tiller counts was found for a single annual bluegrass tiller grown in the center of 4 turfgrass seedlings in Experiment 4. Four seedlings of annual bluegrass competed with the mature tiller of annual bluegrass the greatest limiting tillering to 18.5 mean tillers (Table 6). Citation, Manhattan, and Pennfine offered the most competition limiting tillering to an average 23.1, 33.8, and 42.5 for the center annual bluegrass plant. Kentucky bluegrass seedlings did not offer as much resistance to annual bluegrass tillering as some of the more competitive ryegrasses mentioned above. Poor competitive ability of Kentucky bluegrass seedlings was attributed to the slow establishment rate of Kentucky bluegrasses.

The competitive ability of annual bluegrass seedlings was attributed to rapid establishment and tillering. Compared to turf type perennial ryegrasses and Kentucky bluegrasses tested in these experiments, annual bluegrass exhibited more competitiveness when grown in competition with itself. Differences in tillering and shoot dry weights did exist between the species and within the species tested. Comparing plants propagated from tillers, the bluegrasses were more competitive than the ryegrasses. This was attributed to the fact that bluegrasses had the ability to produce rhizomes. When emerged, rhizomes produced plants separate from the parent plant. The new plants developed and tillered, and produced more rhizomes thereby expanding the number of plants. These plants could exploit the environment close to the parent plant, but one in which the parent plant could not exploit by increased tillering. This process afforded a great advantage over the perennial ryegrasses which do not produce rhizomes.

When ryegrasses and bluegrasses competed as seedlings against annual bluegrasses, some ryegrasses tillered more than bluegrasses. This was attributed to the faster development rate of the ryegrass seedlings. If the seedling experiment had been continued over a longer period of time, it is assumed that the bluegrasses would have eventually proved to be more dominant than the ryegrasses.

The conditions under which these experiments took place should be placed in perspective when interpreting these results. Watering and nutrient feeding were optimum by design for annual bluegrass (2, 3, 4). If environmental conditions had favored annual bluegrass less, the Kentucky bluegrasses or perennial ryegrasses might have been more competitive with annual bluegrass. These experiments were also conducted under a wide initial plant spacing. Competitive effects have been shown to differ with increased densities (15, 19, 48, 64). Only two plant ratios were tested, either a 4:1 turfgrass to annual bluegrass or a 1:4 annual bluegrass to turfgrass ratio. A change in plant ratio could also alter competitive effects.

CHAPTER IV

ETHOFUMESATE TOXICOLOGY

Effect of 5 Rates of Ethofumesate on the Growth Development of 3 Poa pratensis L. Cultivars, 2 Agrostis palustris L. Cultivars, and Poa annua L. Grown in the Greenhouse.

Methods and materials. A greenhouse study was initiated to determine the effect of the herbicide ethofumesate [(-+)2-ethoxy-2,3-dihydro-3,3-dimethylbenzofuron-5-yl-methylsulphonate] on the growth and development of 3 cultivars of *Poa pratensis* L., 2 cultivars of *Agrostis palustris*, and *Poa annua* L.

Mature sods of the grasses tested, grown in Hadley silt loam soil (Typic Udifluvent) on the University of Massachusetts South Deerfield Turfgrass Research Station, were harvested (Table 7). Each sod piece was separated into individual tillers or plants. Tillers were selected visually for uniform shoot and root system size.

Single plants of each turfgrass were planted in sand (Table 8) contained in 473.2 ml polystyrene plastic cups with 4, 0.45 cm holes punched in the bottom to provide drainage. Sand was chosen as a growing media because it could be washed from the roots to facilitate root measurements. Each planting was replicated 8 times for each of the 5 ethofumesate treatments and control for each of the

TABLE 7

TURFGRASSES AND RATES APPLIED IN
ETHOFUMESATE TOXICOLOGY EXPERIMENT

Turfgrasses	Rates Ethofumesate kg/ha Applied to Each Turfgrass
A. Kentucky Bluegrass	
Cultivars	0.42
	0.84
A-34	1.68
Baron	3.36
Touchdown	6.72
	Untreated
B. Creeping Bentgrass	
Penncross	
Penneagle	
C. Weedgrass	
Annual Bluegrass	

TABLE 8

DIAMETER OF PARTICLE, DESCRIPTION OF PARTICLE, AND PERCENT
COMPOSITION: OF SAND USED IN ETHOFUMESATE TOXICOLOGY EXPERIMENT

Diameter (mm)	Description	Percent* of Composition
2.0 - 6.0	gravel	6
1.0 - 2.0	Very coarse sand	23
0.5 - 1.0	Coarse sand	34
0.25 - 0.5	Medium sand	25
0.10 - 0.25	Fine sand	10
0.05 - 0.10	Very fine sand	1
less than 0.005	Silt & clay	< 1

*Percent is an average of three samples analyzed.

6 turfgrasses tested, a total of 288 plantings. Cups were arranged in a completely randomized design in a quonset style plastic greenhouse at the University of Massachusetts, Amherst, Massachusetts. The greenhouse was maintained at 21^{o}C. Grass plants were watered every 2-3 days as needed. Once weekly the plants were fertilized with half strength Hoagland's solution. Turfgrasses were cut at a height of 1.9 cm every 3 days.

Six weeks after planting 5 rates of ethofumesate were applied to the turfgrasses (Table 7). Each rate was applied to 8 replications of each grass tested. The herbicide was applied with a Co_2 small plot sprayer with a boom configuration of 3, 80008 T jet nozzles spaced 48 cm apart. An area 1.5 m wide was covered by the sprayer. The spray volume was 467.7 l/ha, delivered with 3.45×10^5 PA of pressure.

Tiller counts were made and recorded five weeks after treatment. The sand media was carefully washed from the shoots, and roots, and then root length measurements were taken. Roots were removed from shoots and both were placed in their respective labeled bags. All samples were then dried at 70^{o}C in a forced air drying oven. Dry weights of both were subsequently recorded.

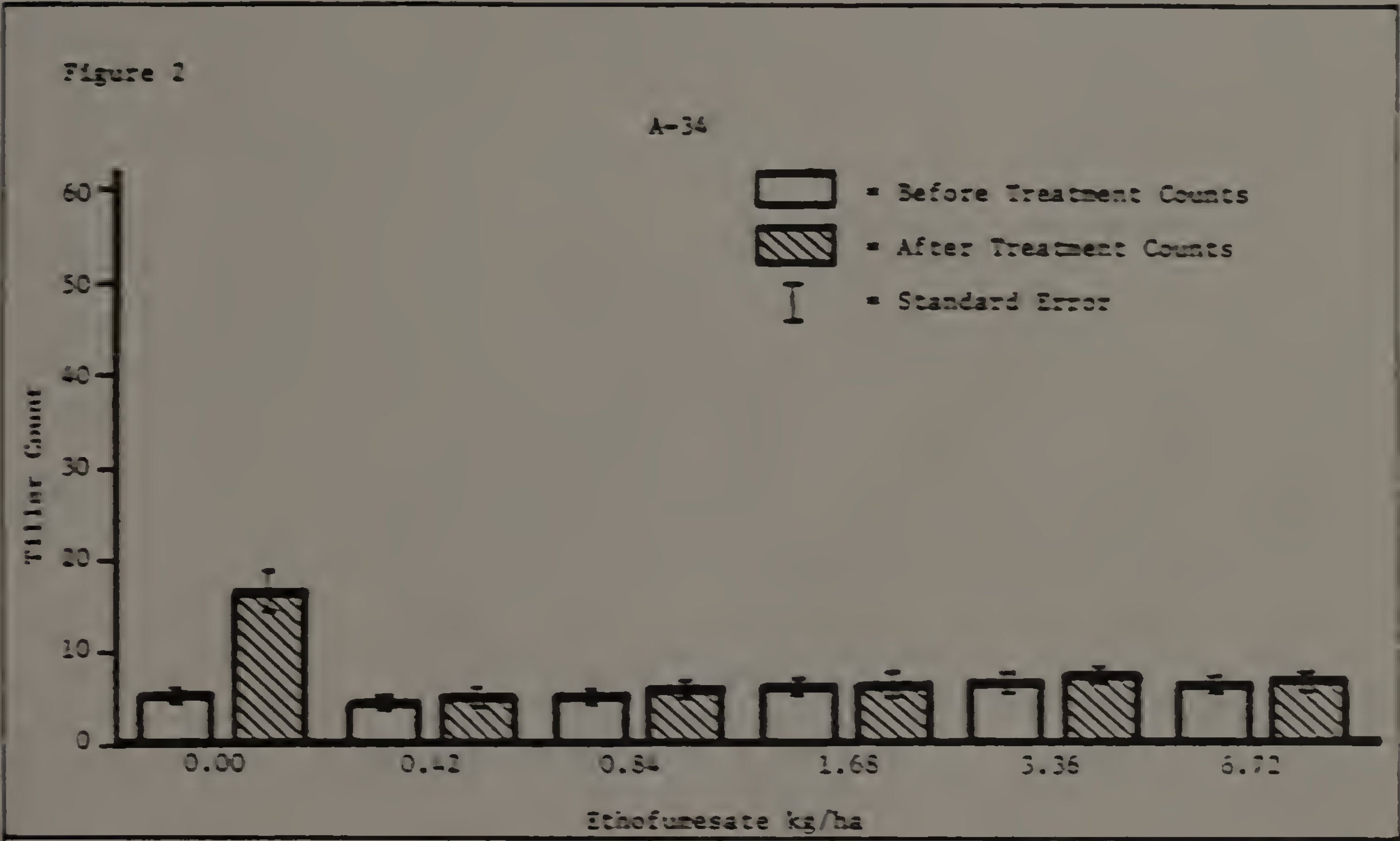
Results. Tillering of all grasses was suppressed by each rate of ethofumesate. The herbicide treated plants were significantly different ($p = 0.00$) from the untreated replications. Tiller counts of the lowest treatment rate, 0.42 kg/ha, were not significantly different from the rest of the treatment rates for all turfgrasses tested.

Tiller counts taken immediately before ethofumesate treatment and tiller counts made 5 weeks after treatment on plants of A-34, Baron, and Touchdown Kentucky bluegrasses had similar values (Figures 2-4). Tiller counts of untreated turfgrass plants were recorded at the same time as those of treated replications. Tiller counts made on untreated grasses 5 weeks after the first tiller counts were larger for all turfgrasses tested. All replications of Kentucky bluegrass were alive at termination. Five weeks after treatment with ethofumesate, some replications of Baron and Touchdown treated with 0.42 kg/ha of the herbicide were starting to show resumption of tillering. A-34 showed no regrowth at termination. New growth was not noted on grasses treated with rates greater than or equal to 0.84 kg/ha of ethofumesate. A darker green color was observed on all treated replications of Kentucky bluegrass cultivars.

Annual bluegrass treated with ethofumesate discontinued tillering regardless of rate (Figure 5). Yellowing of half of the annual bluegrass replications treated with either the 1.68, 3.36, or 6.72 kg/ha rate was noted. One plant of each of the 0.84 and 1.68 kg/ha treatment rates died by termination of the experiment. Tillering of annual bluegrass was not evident on any treated replications.

Tillering was noted on creeping bentgrasses treated with the lowest ethofumesate rate. It was observed that approximately half

Fig. 2 + 3. Mean Tiller Count of A-34 (Figure 2) and Baron (Figure 3) Before and After Treatment with 5 Rates of Ethofumesate and Control.



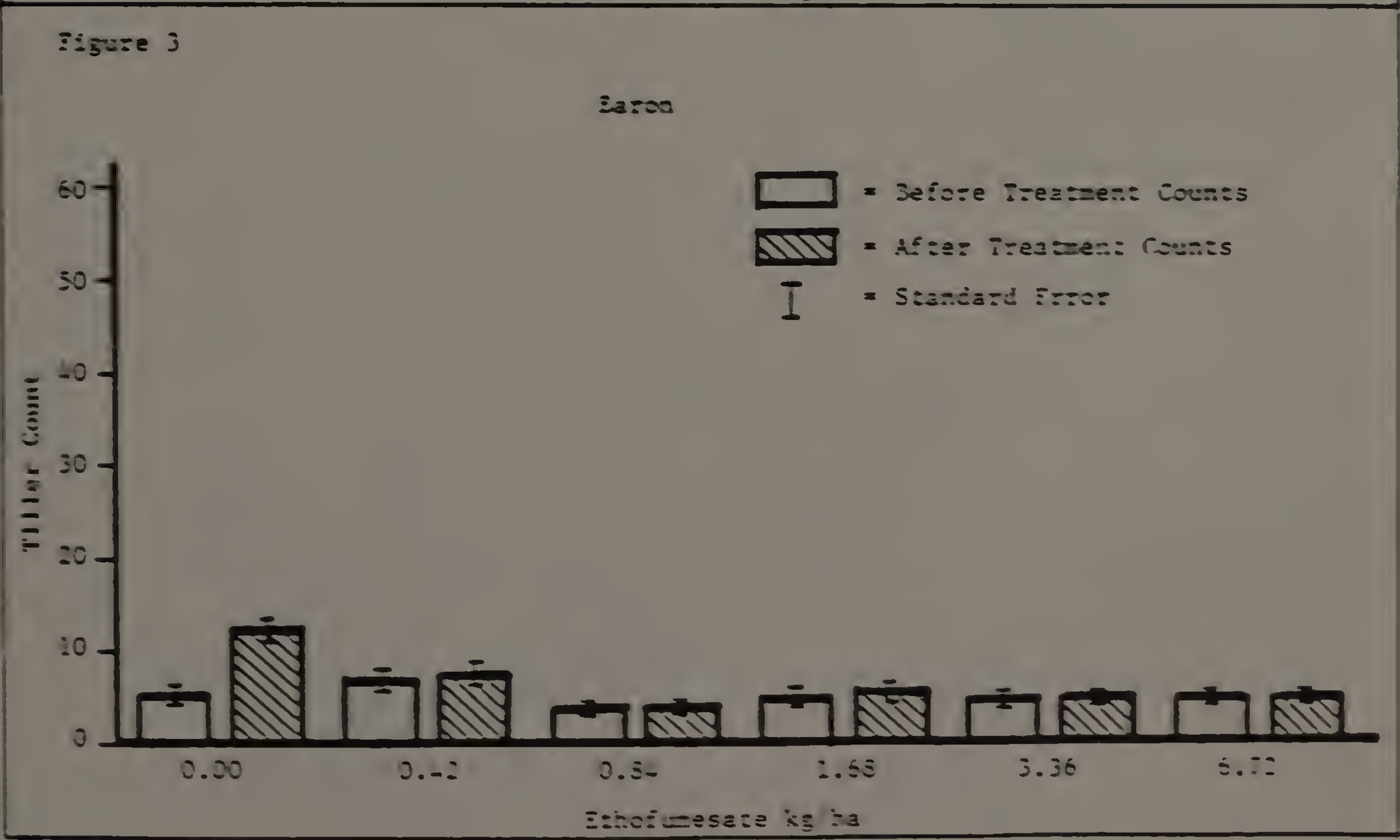
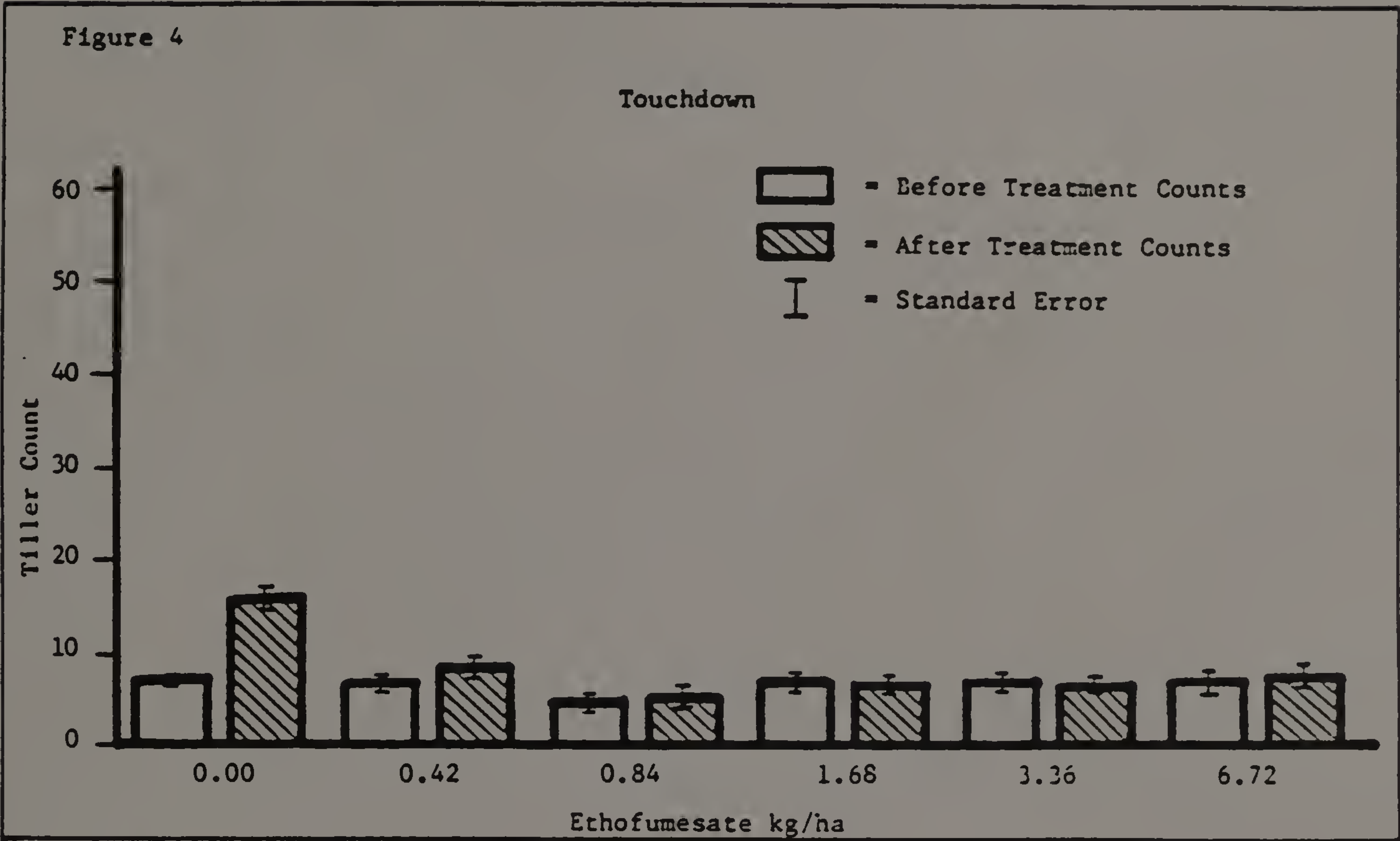
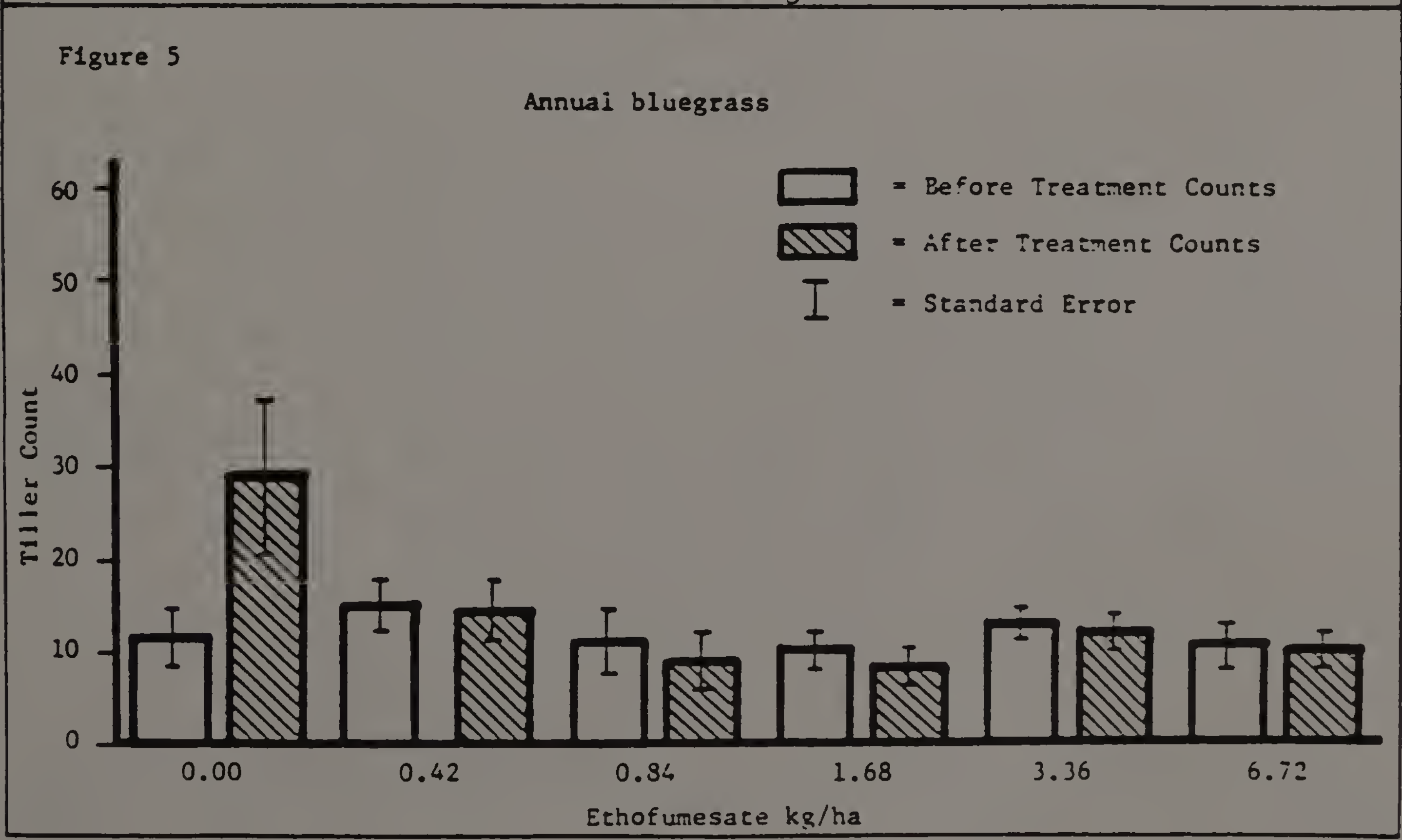


Fig. 4 + 5. Mean Tiller Count of Touchdown (Figure 4) and Annual Bluegrass (Figure 5) Before and After Treatment with 5 Rates of Ethofumesate and Control.



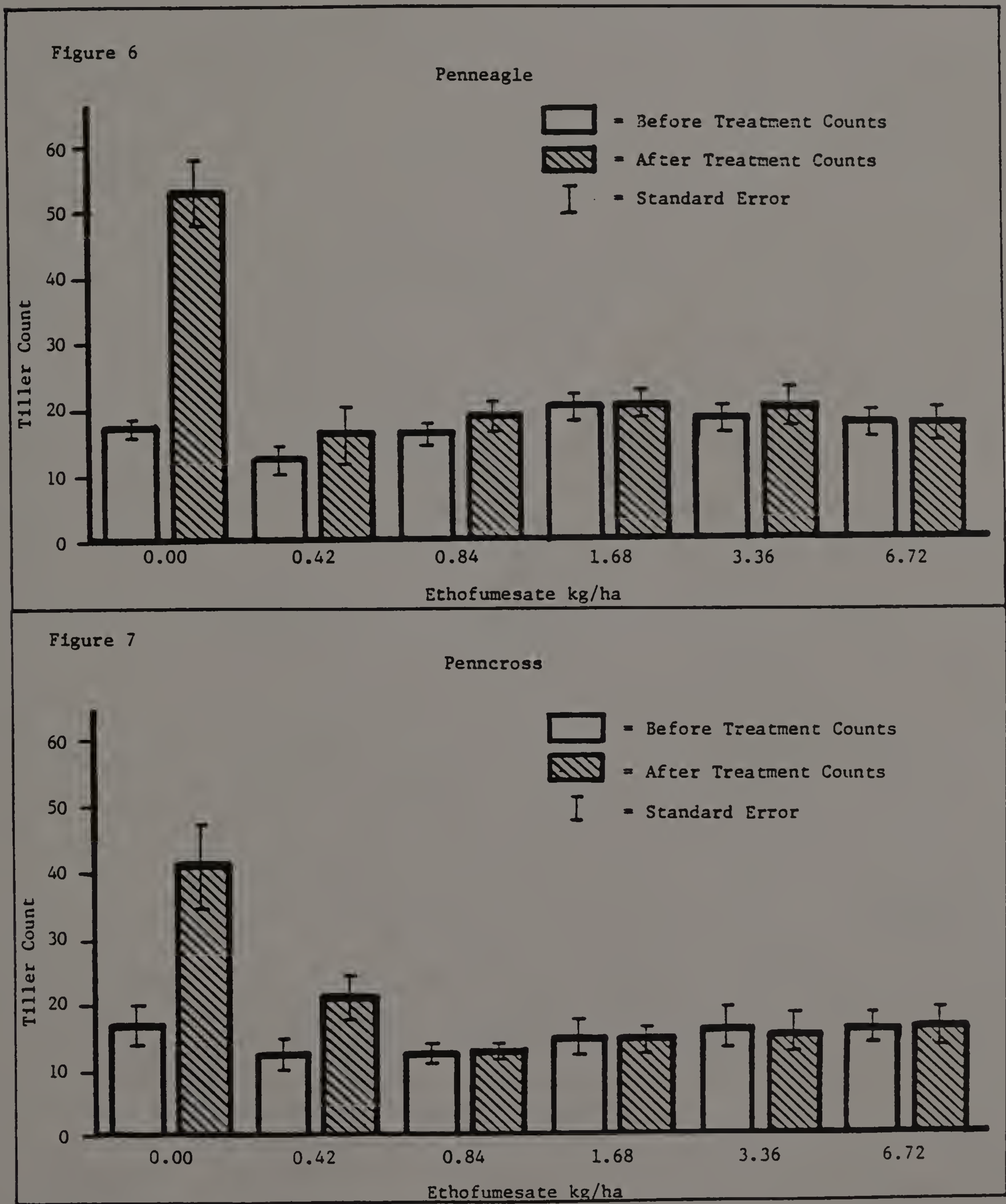


the replications of Penneagle and Penncross creeping bentgrass treated with 0.42 kg/ha of ethofumesate had resumed tillering 5 weeks after treatment. Penneagle creeping bentgrass after treatment tiller counts at the 0.42 kg/ha rate were almost twice as great as the before treatment tiller counts (Figure 6). This effect was not evident at the other treatment rates. The after treatment tiller counts of Penncross creeping bentgrass at the 0.42 kg/ha rate were also greater than the before treatment counts (Figure 7), but the increase was not as great as Penneagle.

Mean shoot dry weights of treated turfgrasses were significantly different ($p = 0.00$) from untreated plants for all grasses. The lowest treatment rate, 0.42 kg/ha, compared to other treatment rates was significantly different ($p = 0.04$). Shoot dry weights of plants treated with rates of 0.84 kg/ha and greater were not significantly different from each other.

Penncross creeping bentgrass shoot dry weights of replications treated with the 0.42 kg/ha rate were greater than other ethofumesate treatments (Figure 8). Penneagle creeping bentgrass showed a reduction in mean shoot dry weight at the 0.42 kg/ha rate compared to other treatments. Mean shoot dry weights of A-34 and Touchdown Kentucky bluegrass did not vary much among treatment rates (Figure 8). However, Baron Kentucky bluegrass that received the lowest rate of the herbicide produced a larger mean shoot dry weight at the 0.42 kg/ha rate compared to the other treatment rates (Figure 8). Annual bluegrass exhibited similar trends in

Fig. 6 + 7. Mean Tiller Counts of "Penncross" (Figure 6) and "Penneagle" (Figure 7) Before and After Treatment with 5 Rates of Ethofumesate and Control.



mean shoot dry weights as did Baron. The mean shoot dry weights of all untreated replications were the greatest.

Tiller counts of untreated Penneagle creeping bentgrasses were over 2 times larger than treated plants (Figure 7). Shoot dry weights of untreated Penneagle plants were comparable to the shoot dry weight for the treated replications (Figure 8). Penncross exhibited the same results. In contrast, untreated replications of annual bluegrass plants which exhibited increased tiller numbers had a corresponding increase in shoot dry weight (Figure 8). The relationship between tillering and shoot dry weight was not as clear in the Kentucky bluegrass cultivars. Untreated Kentucky bluegrass plants which had more tillers than treated grasses exhibited a small increase in mean shoot dry weight.

All chemically treated grasses had significantly different mean root dry weights ($p = 0.06$) compared to the controls. Mean root dry weights were not significantly different between the treatment rates. Obvious trends of treatment effects on Kentucky bluegrass root dry weight data were not evident (Figure 9). Smaller mean root dry weights for untreated replications of bentgrass cultivars were noted (Figure 9). Penneagle creeping bentgrass treated with 0.42 kg/ha of ethofumesate exhibited a reduced mean root dry weight. Mean root dry weights of annual bluegrass varied with treatment rates.

Mean root lengths of all treated replications were significantly shorter ($p = 0.00$) than untreated grasses. Root lengths of

Fig. 8. Mean Shoot Dry Weight in Grams of A-34, Baron, Touchdown, Annual Bluegrass, Penncross, and Penneagle After Treatment with 5 Rates of Ethofumesate and Control. I = Standard error.

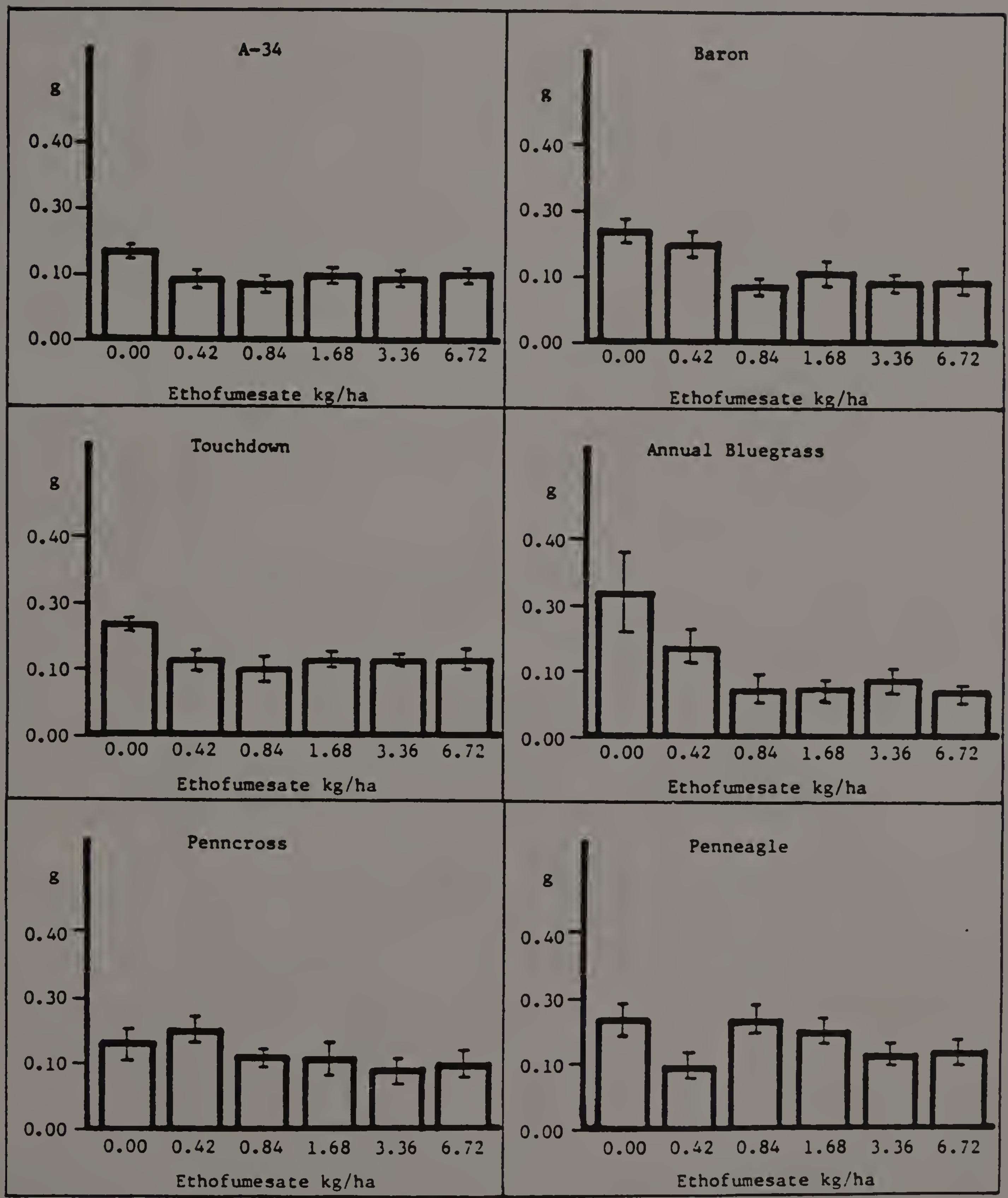
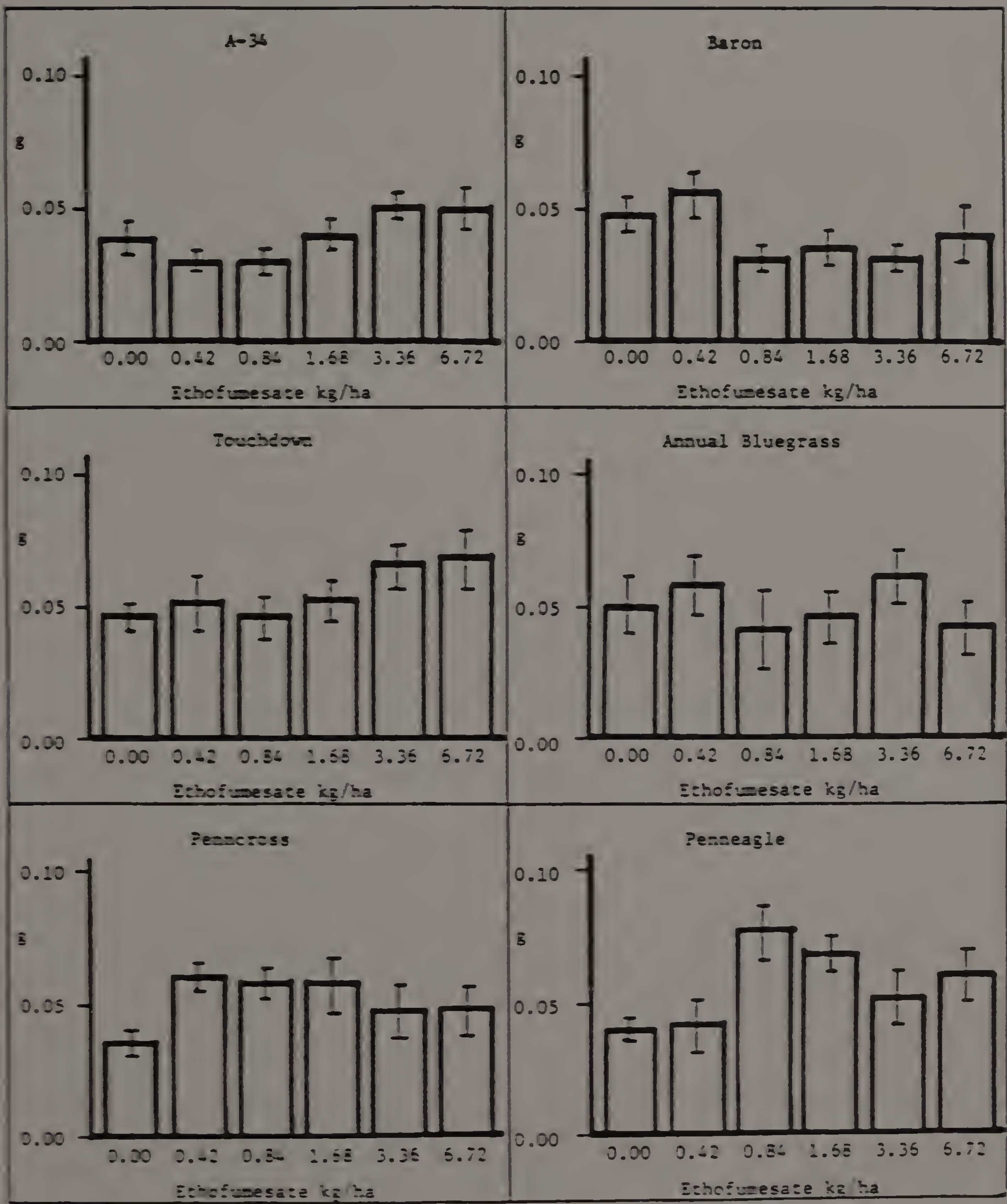


Fig. 9. Mean Root Dry Weight in Grams of A-34, Baron, Touchdown, Annual Bluegrass, Penncross, and Penneagle After Treatment with 5 Rates of Ethofumesate and Control. I = Standard error.



turfgrasses treated with 0.42 kg/ha rate of ethofumesate were significantly different ($p = 0.02$) from the other treatment rates. Root length varied with treatment rates on the Kentucky bluegrass cultivars tested (Figure 10). The data indicates annual bluegrass and Penncross creeping bentgrass treated with 0.42 kg/ha of ethofumesate had longer roots than other treated grasses, or untreated grasses.

Abnormal growth was observed in the crown tissue of the creeping bentgrasses regardless of the treatment rate (Figure 11). The tissue appeared swollen and dense. Masses of green cells that appeared to be undifferentiated were observed growing at the nodes on the stolons (Figure 11). Tillering was observed from the abnormal nodes of the bentgrasses treated with 0.42 kg/ha of ethofumesate. Tillering from these growth gave the plant a witches broom effect. Roots were also initiated from the abnormal growth on the stolons. Crown tissue of annual bluegrass and all the Kentucky bluegrasses treated with ethofumesate also exhibited abnormal growth (Figures 12 and 13). The crown tissue became lumpy and dense. Masses of undifferentiated cells similar to those observed on the nodes of bentgrass stolons were observed originating from the crown. Masses of cells were also noted on the nodes of some Kentucky bluegrass rhizomes (Figure 13).

Discussion. The objective of this study was to determine the effects of 5 rates of ethofumesate on the growth and development of desirable turfgrass cultivars. Tillering was suppressed by all

Fig. 10. Mean Root Length in Centimeters of A-34, Baron, Touchdown, Annual Bluegrass, Penncross, and Penneagle After Treatment with 5 Rates of Ethofumesate and Control. I = Standard error.

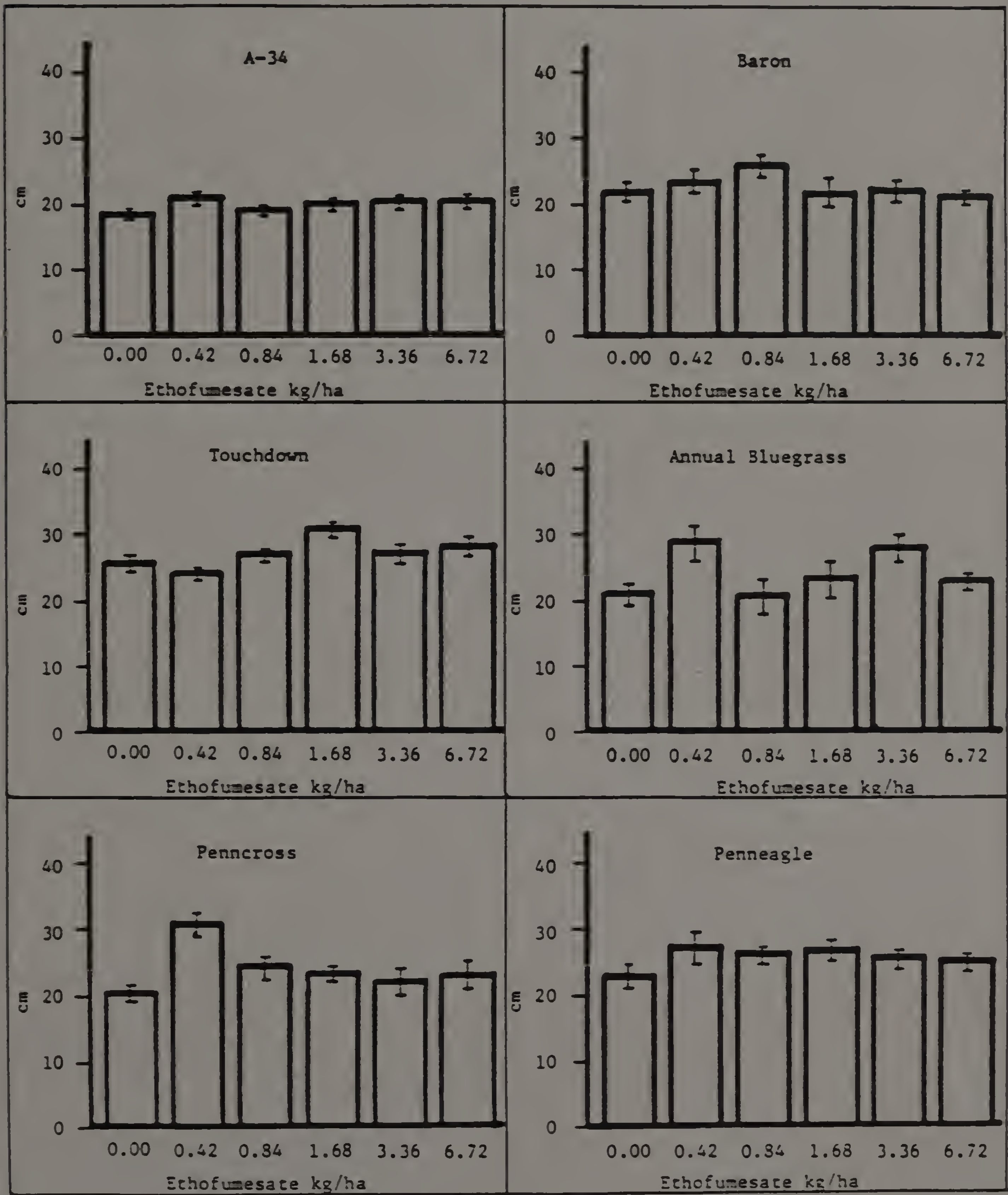


Fig. 11. Abnormal growth of crown tissue and nodes of stolons on 'Penncross' creeping bentgrass treated with 0.84 kg/ha of ethofumesate.

Fig. 12. Abnormal growth of crown tissue of *Poa annua* L. treated with 0.42 kg/ha of ethofumesate.

Fig. 13. Abnormal growth of crown tissue and rhizomes on A-34 treated with 6.72 kg/ha of ethofumesate (right plant), and control (left plant).

ethofumesate treatment rates on all grasses tested. This indicates that ethofumesate affected the meristematic tissue of the plant. A similar finding by Pfeiffer (44) concurs with tillering inhibition. He found that mitosis in apical meristems of wild oats was inhibited to some degree by ethofumesate. Visual observations also provided evidence of ethofumesate effects on growing plants. Undifferentiated green cells were observed at the nodes on stolon of the creeping bentgrasses. The lowest treatment rate exhibited abnormal tillering and root growth from the masses of cells on the bentgrasses. Crown tissue of Kentucky bluegrass and annual bluegrass treated with ethofumesate exhibited abnormal growth. Masses of undifferentiated cells made the crown tissue lumpy and dense. It is probable that ethofumesate affected the plant hormone relationships thereby inhibiting root and shoot formation and causing abnormal growth.

Since tillering of untreated turfgrasses was greater than grasses treated with ethofumesate, it would be expected that increased tillering would be reflected in corresponding increased shoot dry weights. Although shoot dry weights of untreated replications were significantly larger than treated, the shoot dry weights did not reflect the 2-fold increase of tiller counts for untreated plants (Figure 8). Untreated creeping bentgrasses had twice as many tillers than treated plants, but the shoot dry weights were not greater for the untreated replications. Shoot dry weights of untreated Kentucky bluegrass cultivars were slightly larger than treated plants, but the increase was not as large as increased tillering. Annual bluegrass however, had a corresponding increase in mean shoot dry weight for increased tillering of the control.

Several possible explanations exist for the lack of differences in shoot dry weights between treated and untreated grasses. One explanation could be that weight per tiller of treated replications was increased since no new tillers were produced to utilize the products of photosynthesis. A more probable hypothesis is that the increase in dry weights of treated replications was related to the masses of undifferentiated tissue found on stolons and crown tissue of the bentgrasses, and the crown tissue of the bluegrasses. It is also possible that both factors affected shoot dry weight.

Differences in mean root dry weight between treated and untreated grasses were hard to distinguish. Root dry weights of treated replications were significantly different from the untreated turfgrasses ($p = 0.06$). The significance was probably due to smaller root dry weights for untreated bentgrass cultivars (Figure 10). Trends in mean root dry weights of the bluegrass cultivars and annual bluegrass were not easy to discern.

The mean root lengths of treated plants were significantly longer than untreated replications ($p = 0.00$). Mean root lengths of the 0.42 kg/ha rate of ethofumesate were significantly different ($p = 0.02$) from other treatment rates, although it was not evident in the data whether the difference was an increase or decrease in root length (Figure 10). As in the case of mean root dry weights of untreated plants, the significantly shorter mean root lengths of untreated replications were mainly evident in the creeping bent-grasses.

It was evident that ethofumesate had a detrimental effect on shoot growth on all the turfgrasses. However, it must be remembered that to facilitate the collection of data on root growth this experiment was conducted using a sand growing media. The sand media had two properties that could affect the results. The lack of organic matter could have made the effects of the herbicide more severe than if organic matter was present. It has been noted by investigators (26, 31, 53, 54) that effects of ethofumesate were reduced with increased organic matter content of the soil. The other factor affecting herbicide activity could have been the lack of soil microbes. Although the sand was not sterilized in the experiment, it is a fairly inert material compared to soil. Increased microbial activity has been shown to reduce the life of ethofumesate in the soil (31, 55). It is possible that ethofumesate applied under the same conditions on the grasses growing in an unsterilized loam soil could have different results. An interesting study would be to compare results from an experiment similar to this one with the only difference in methodology being a change from a sand media to a loam soil.

The results of this study indicate that ethofumesate affects the growth and development of the grass plants. Ethofumesate has the potential to limit growth of these species in the field by reducing tillering. It has been shown that a reduction in tillering reduces competitive ability of the stand (15, 35, 48, 51), and threatens the longevity of the stand (34, 36). If ethofumesate was used on these turfgrasses in the field, and a severe reduction in tillering occurred, the turf would probably be more susceptible to diseases, insects, and weeds. The results of this study indicate investigation into the long term effects of ethofumesate treatments on established sod should be made before it is used on these turfs.

CHAPTER V

FIELD EXPERIMENTS

Experiment 1: Conversion of a Poa annua L. Infested Gold Tee to Lolium perenne L. With Overseeding and Ethofumesate Treatments

Methods and materials. Field Experiment 1 was designed to investigate the use of ethofumesate [(-+)2-ethoxy-2,3-dihydro-3,3-dimethylbenzofuron-5-yl-methylsulphonate], treatments in conjunction with a *Lolium perenne* L. overseeding program to transform a predominatly *Poa annua* L. turf stand on a golf tee to a stand that was predominately ryegrass. It was also the objective of this experiment to achieve this result without removing the tee from play.

The study was initiated on the 9th tee Amherst Golf Club, Amherst, Massachusetts during the last week of August 1980. The stand composition of the turf was estimated to be 90-95% annual bluegrass at the beginning of the study. Immediately prior to herbicide treatments the tee was cultivated with a coring machine (Table 9). Cores were dragged with a chain link fence and deposited plant material was removed by raking. Following removal of organic material the tee was broadcast seeded with Manhattan perennial ryegrass at a rate of 384 kg/ha and dragged again with a chain link fence (Table 9).

An area 9.0 m by 18.6 m was squared off on the tee and divided

TABLE 9

DATES, CORING, PERENNIAL RYEGRASS SEED, RATE, METHOD OF SEEDING; FIELD EXPERIMENTS 1 AND 2 - 1980, 1981, 1982.

Dates	Coring	Perennial Ryegrass Seed	Rate kg/ha	Method of Seeding
8/28/80*		Manhattan	390	Broadcast
8/28/80**	√	Manhattan	195	Broadcast
9/24/80		Manhattan	195	Sliced
10/3/80		Blend+	195	Sliced
10/28/80	√	Blend	146	Broadcast
4/28/81	√	Blend	146	Broadcast
5/17/81		Blend	146	Sliced
6/15/81		Blend	146	Sliced
8/24/81	√	Manhattan	195	Broadcast
8/26/81		Blend	146	Sliced
9/10/81		Blend	146	Sliced
9/25/81		Manhattan	146	Sliced
10/8/81	√	Blend	146	Broadcast
4/22/82		Manhattan	195	Sliced
5/20/82	√	Manhattan	195	Sliced

*5th Tee only

**9th Tee only

+Blend = 1/3 Citation, 1/3 Manhattan, 1/3 Omega perennial ryegrass.

into 3 replications. Each replication contained 12 treatment plots measuring 1.5 m by 3.1 m. Three pre-emergence treated plots, 3 post-emergence treated plots, 3 combination pre- and post-emergence treated plots, and 3 untreated plots were arranged in a completely randomized block design within each replication. Pre-emergence and post-emergence designations were in respect to annual bluegrass germination times, not germination of ryegrass that was overseeded.

Pre-emergence ethofumesate treatments were applied at 3 rates on the same day that the turf was overseeded with Manhattan perennial ryegrass (Table 10). Four weeks after the pre-emergence treatments were applied, the site was again overseeded with a slice seeder (Table 9). Organic material left by seeding was raked off prior to applications of post-emergence treatments of ethofumesate at 3 rates (Table 10). Two other seedings were carried out in October 1980 (Table 9).

Coring, overseeding, and pre-emergence treatments were repeated at the end of April 1981 (Tables 9 and 10). Overseeding and post-emergence treatments were carried out 4 weeks later at the end of May (Tables 9 and 10). The tee was also overseeded in mid June. Coring, seeding, and herbicide treatments were carried out again in late August and late September of 1981 in the same manner as in 1980. Overseeding was carried out 3 times during the later part of the 1981 growing season in addition to seedings that were conducted prior to ethofumesate treatments (Table 9). Spring overseeding and herbicide treatments were carried out in late April

TABLE 10

TREATMENT RATE OF ETHOFUMESATE AND TIME OF TREATMENT IN FIELD EXPERIMENTS 1, 2, AND 3.

Treatment Rate of Ethofumesate kg/ha	Time of Treatment
0.84	Pre-emergence*
1.12	Pre-emergence
1.68	Pre-emergence
0.84	Post-emergence**
1.12	Post-emergence
1.68	Post-emergence
0.84 + 1.68	Pre + Post-emergence
1.12 + 1.12	Pre + Post-emergence
1.68 + 0.84	Pre + Post-emergence
0.00	Untreated Control

*Pre-emergence treatments were applied on 8/28/80, 4/17/81, 8/26/81, and 4/22/82.

**Post-emergence treatments were applied on 9/24/80, 5/20/81, 9/25/81, and 5/21/82 four weeks after Pre-emergence treatments.

and late May of 1982 (Tables 9 and 10).

The 9th tee received 7 fertilizations, a total of 146.5 kg/ha of nitrogen in 1980, and 8 applications in 1981 for a total of 125 kg/ha of nitrogen (Table 14). One 36.6 kg/ha application of nitrogen was made in June of 1982. Mowing was carried out 3 times weekly in 1980 and 1981 at a height of 1.9 cm until mid June when the cutting height was increased to 2.5 cm. In mid August the 1.9 cm cutting height was resumed. The turf was maintained at 1.9 cm during 1982. Betasan was applied in late April of 1980 and 1981 for crabgrass control. Tri-Mec Bentgrass Formula was applied in late May of 1980 and early June of 1981 for broadleaf weed control (Table 15). Five fungicide applications were made in each of 1980 and 1981 on the tee (Table 15). Pesticide treatments other than ethofumesate were not applied in 1982.

Each plot was visually rated at the end of each month June-October 1981, and May-August 1982, on a scoring scale based on stand composition estimates. A score of 1.0 was given to a stand with a composition of 100% annual bluegrass. Stands composed of 100% perennial ryegrass were rated as 9.0; a 50% ryegrass, 50% annual bluegrass stand was given a score of 5.0. Scores were visual estimates of the percent composition of annual bluegrass shoots and percent perennial ryegrass shoots in the turf canopy. Data was analyzed using Duncan's Multiple Range Test.

Results. Mean scores of 2.6, 3.1, and 4.4 for turfgrass treated with 0.84, 1.12, and 1.68 kg/ha ethofumesate pre-emergence treatments were recorded for the 1981 growing season (Table 11). Turf treated with the same rates of the herbicide in 1982 had mean scores of 4.3, 4.6, and 6.1 (Table 11). Untreated control plots had stand composition estimates of 2.1 and 3.2 for 1981 and 1982 respectively. The 0.84 and 1.12 kg/ha pre-emergence replications were not significantly different from the untreated plots in 1981. Turf treated with the 1.68 kg/ha rate was significantly different from grass in the control plots and from the grass that received lower pre-emergence rates in 1981. In contrast, all the turf sprayed with ethofumesate pre-emergence treatments were significantly different from the control in 1982. Turfgrass that received the 1.68 kg/ha pre-emergence treatment had a mean score of 6.1 which was significantly different from the grass treated with the 0.84 and 1.12 kg/ha.

Figures 14 and 15 illustrate the 1981 and 1982 pre-emergence treatment data graphed over time. Week 6 in 1981 corresponds to the end of June, or 6 weeks after the post-emergence treatment in late May. Through the summer months scores remained fairly constant. A dramatic increase in the stand composition estimate for the highest rate tested was observed the last week of September 1981 (week 19). The score increased from approximately 3 to 7 (Figure 14). Data related to treatment rates collected at the end of May 1982 was similar to that obtained in the fall of 1981, but with slightly lower values (Figure 15). Through the summer of 1982 a gradual increase in score was noted on turf that received pre-emergence treatments of 0.84 or 1.12 kg/ha. Turf treated with these rates

TABLE 11

TREATMENT TIME, ETHOFUMESATE RATES, AND MEAN SCORE, EXPERIMENT 1 - 1981 AND 1982.

Treatment Time	Ethofumesate Rates kg/ha	Mean Score* 1981	Mean Score* 1982
Pre-emergence	0.84	2.6a++	4.3b++
Pre-emergence	1.12	3.1a	4.6b
Pre-emergence	1.68	4.4b	6.1cd
Post-emergence	0.84	4.8bc	5.5c
Post-emergence	1.12	5.7cd	6.6de
Post-emergence	1.68	5.9d	6.8de
Pre + Post emergence	0.84 + 1.68	7.6e	8.1f
Pre + Post emergence	1.12 + 1.12	7.8e	8.1f
Pre + Post emergence	1.68 + 0.84	6.1d	7.5e
Untreated	0.00	2.1a	3.2a

*Scoring Scale = 1.0 → 5.0 → 9.0

Score	=	% Stand Composition
1.0	=	100% Annual bluegrass
5.0	=	50% Annual bluegrass, 50% Ryegrass
9.0	=	100% Ryegrass

++Values within columns followed by same letter are not significantly different at the 5% level.

Fig. 14. Mean scores over time of turfgrass treated with pre-emergence ethofumesate application and control, Experiment 1 - 1981.

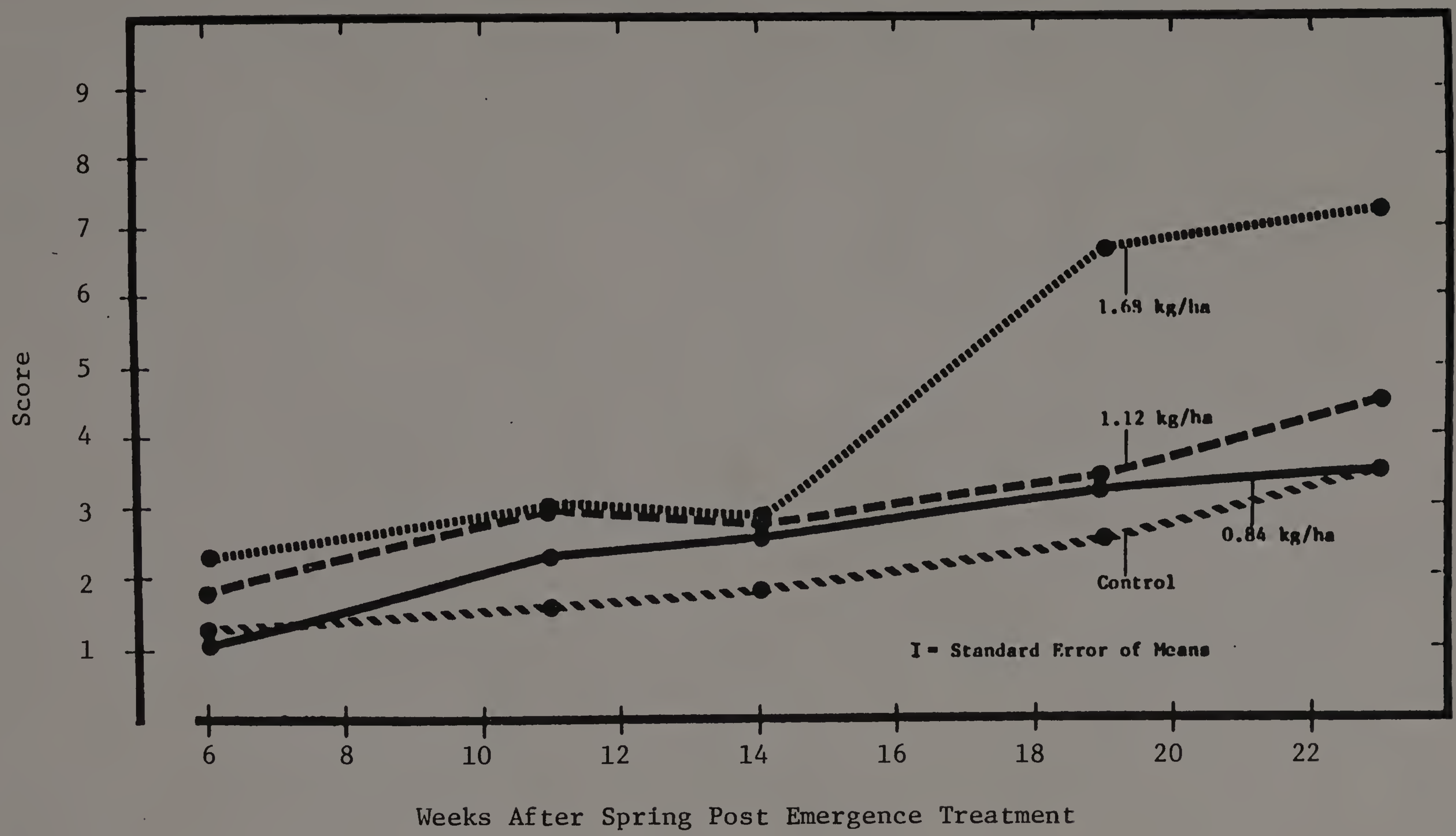
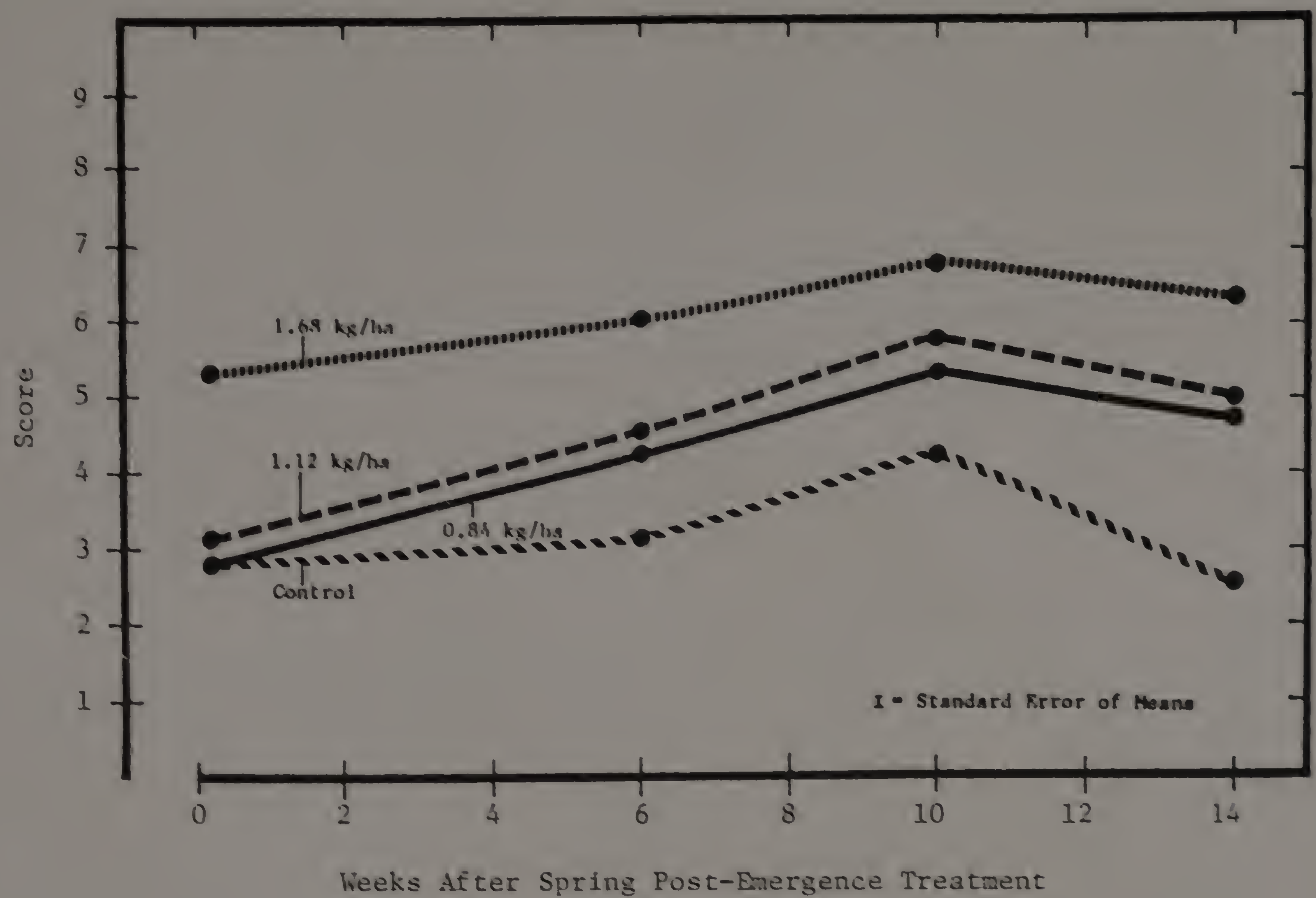


Fig. 15. Mean Scores Over Time of Turfgrass Treated with Pre-emergence Ethofumesate Applications and Control, Experiment 1 - 1982.



showed a relatively greater increase in score than grass to which the 1.68 kg/ha treatment was applied.

Most 1981 and 1982 ethofumesate post-emergence treatment ratings were greater than pre-emergence treatment results (Table 11). Mean 1981 scores were 4.8, 5.7, and 5.9 for turfgrass treated with the 0.84, 1.12, and 1.68 kg/ha rates respectively. The lowest rate score was not significantly different from the highest pre-emergence result. Turf treated with the 1.12 kg/ha or the 1.68 kg/ha post-emergence rate in 1981 had results that were significantly greater than stand composition estimates of pre-emergence treatments. Post-emergence treatment scores in 1982 were significantly different from the two lowest pre-emergence treatment values, but they were not significantly different from turf that received the 1.68 kg/ha pre-emergence treatment. Ethofumesate post-emergence applied to grass plots at the rates of 0.84, 1.12, and 1.68 kg/ha resulted in scores of 5.5, 6.1, and 6.8 in 1982 (Table 11).

Differences in 1981 values between turfgrass sprayed with post-emergence treatment rates at the end of June (week 6) remained throughout the summer (Figure 16). Grass treated with the lowest rate averaged a score of 4 and the highest treatment rate averaged 7 until week 17. Differences in the results were negligible by the end of September 1981. Post-emergence scores in 1982 graphed over time showed the 0.84 kg/ha rate stand composition estimate was more than 2 units less than the 2 higher rates in May (Figure 17). By the end of August 1982 all treatment mean scores were about the same.

Fig. 16. Mean Scores over Time of Turfgrass Treated with Post-emergence Ethofumesate Application + Control, Experiment 1 - 1981.

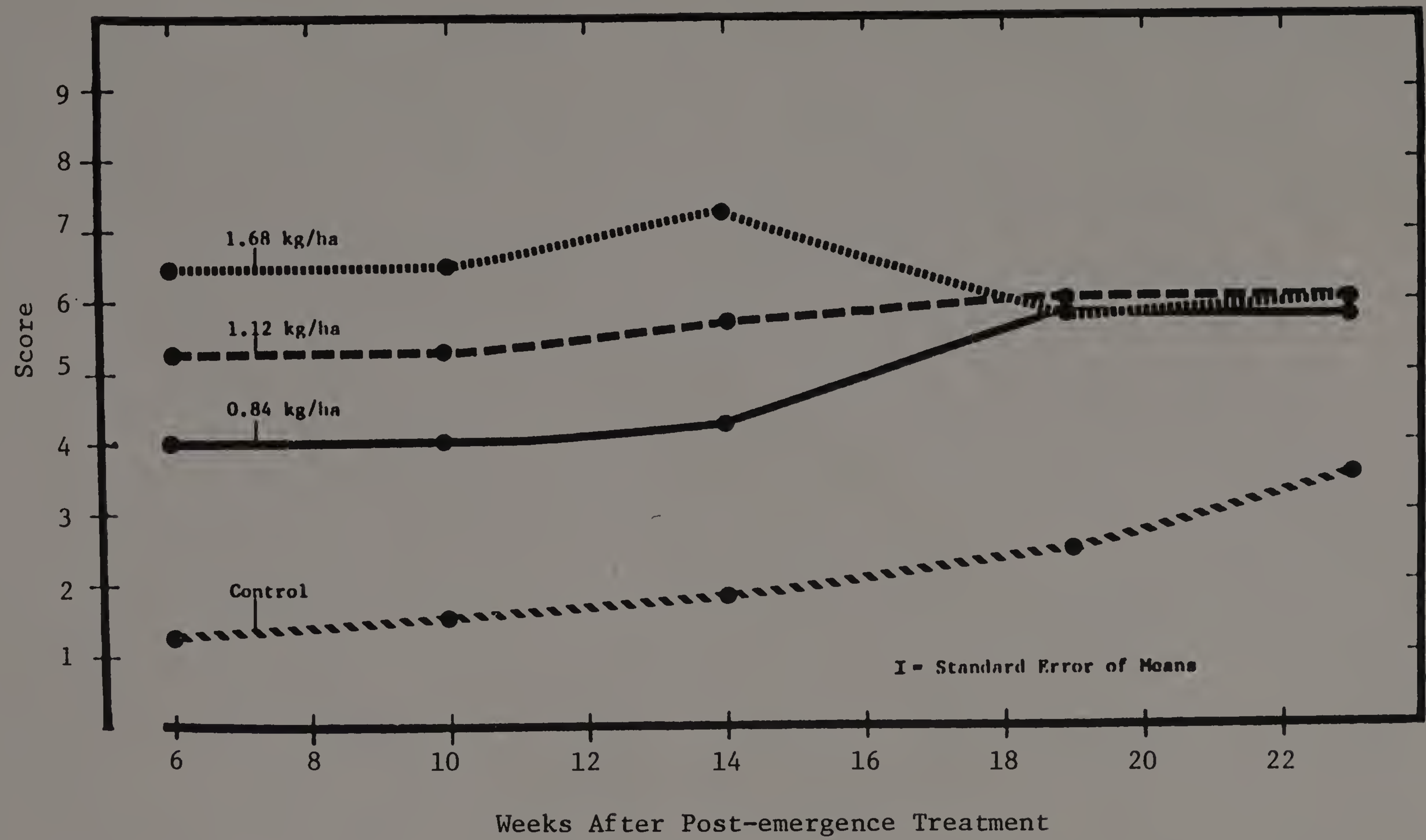


Fig. 17. Mean Score Over Time of Turfgrass Treated with Post-emergence Ethofumesate Applications + Control, Experiment 1 - 1982.

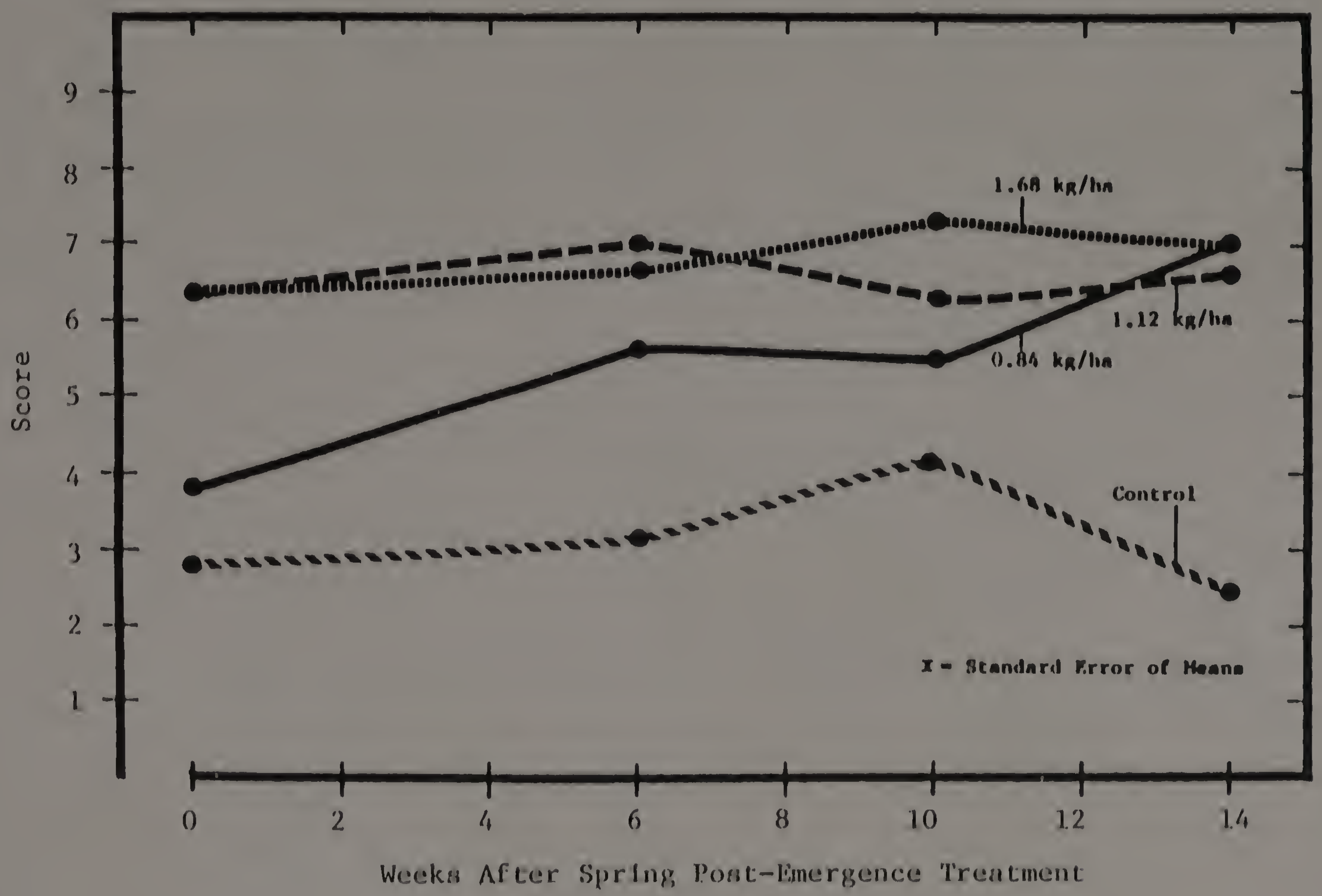
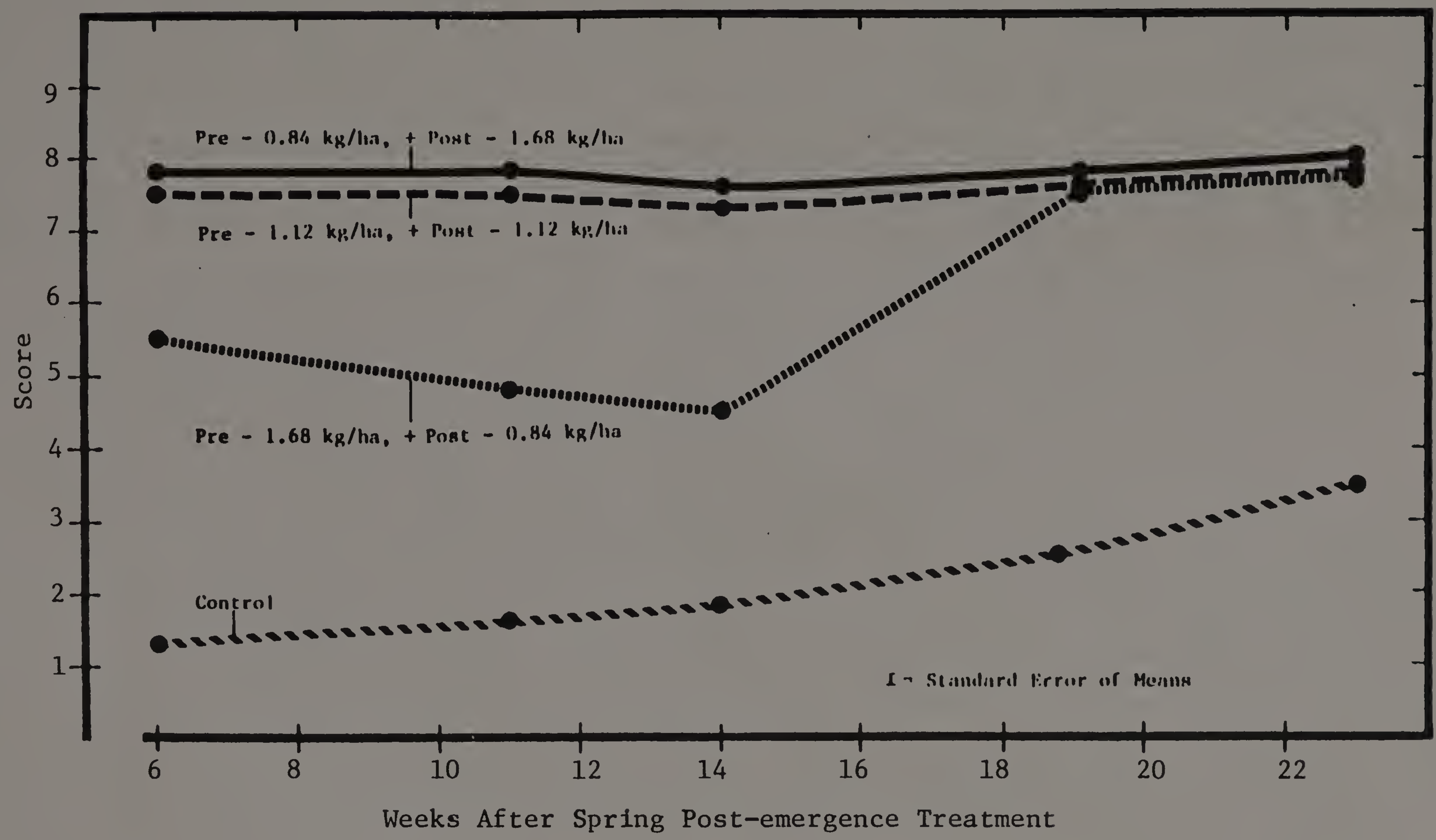


Fig. 18. Mean Scores over Time of Turfgrass Treated with Both Pre- and Post-emergence Ethofumesate Applications + Control, Experiment 1 - 1981.

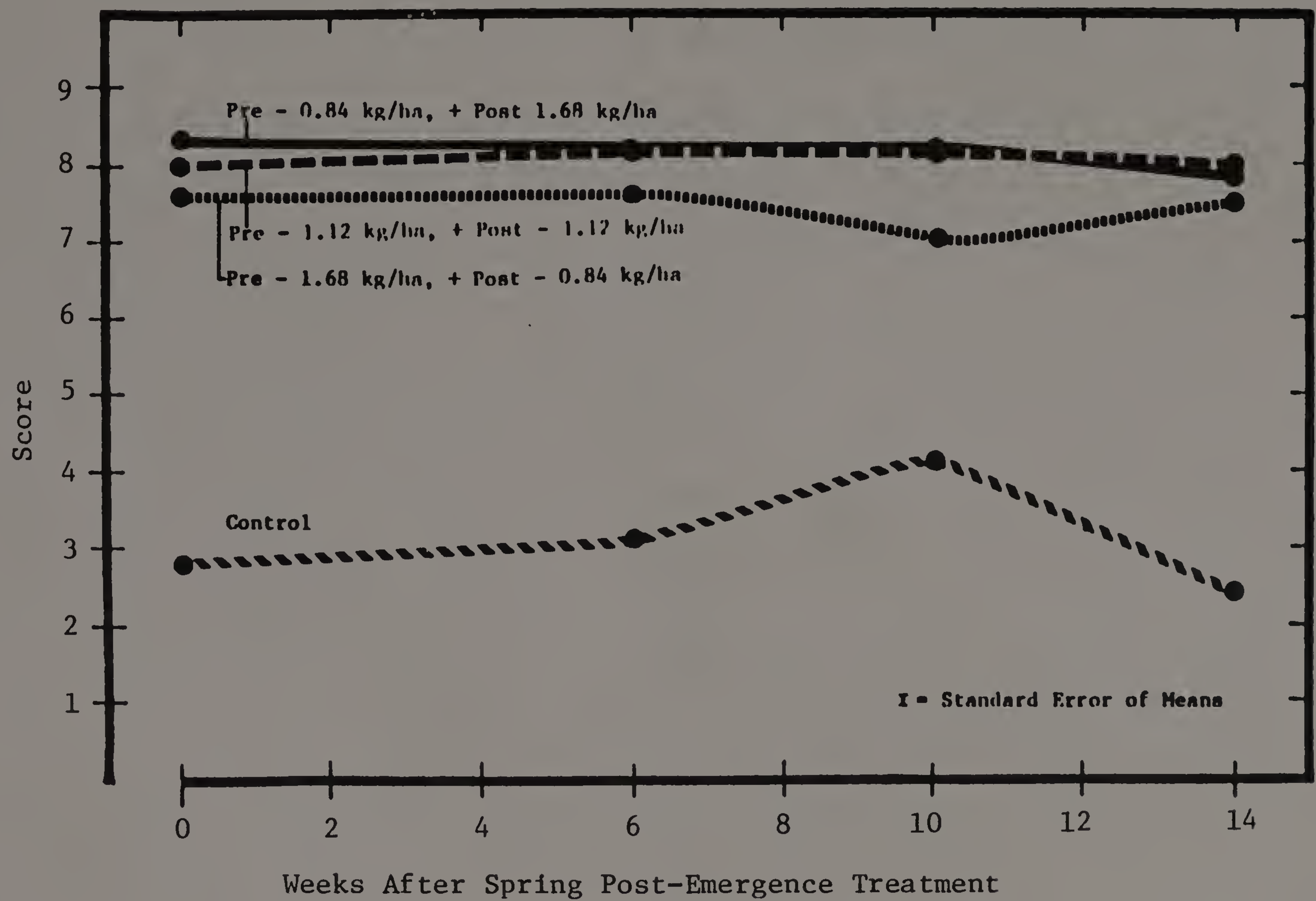


Turfgrass treated with both pre- and post-emergence treatments on the 9th tee had the highest stand composition estimates in 1981 and 1982 (Table 11). Plots that received a 1.68 kg/ha pre-emergence and a 0.84 post-emergence treatment resulted in significantly lower values than turf that received the other pre- and post-emergence treatments. Grass treated with both pre- and post-emergence applications of 0.84, and 1.68 kg/ha of ethofumesate, and those that received both the pre- and post-emergence treatments at rates of 1.12, and 1.12 kg/ha had average ratings of 7.6 and 7.8 in 1981 (Table 11). Turf sprayed with these 2 treatments both had average scores of 8.1 in 1982.

Examining 1981 results over time of turf that received both pre- and post-emergence treatments at rates of 1.68 and 0.84 kg/ha differed from the other treatments until the end of September (week 19) (Figure 18). Scores of 1982 data graphed over time were constant from May to August (Figure 19).

A swale on the 9th tee existed in the middle of the second replication through the 1.12 kg/ha pre-emergence plot, the 0.84 and 1.68 kg/ha post-emergence plots, and the pre- and post-emergence 1.12, 1.12 kg/ha plot. It was noted that the turf stand in the swale was almost 100% annual bluegrass. The rest of these plots were predominately ryegrass. The presence of more annual bluegrass in the swale lowered the scores for these plots. The October 1981 mean value for turf that received both pre- and post-emergence treatments of 1.12, and 1.12 kg/ha was 6.5. If the swale had not

Fig. 19. Mean scores Over Time of Turfgrass Treated with Both Pre- and Post-emergence Ethofumesate Applications + Control, Experiment 1 - 1982.



been present the score could have been 8.5.

Experiment 2: Prevention of Poa annua L. Infestation in a Lolium perenne L. Golf Tee with Overseeding and Ethofumesate Treatments.

Methods and materials. Field Experiment 2 was designed to investigate the use of ethofumesate [(+-)2-ethoxy-2,3-dihydro-3,3-dimethylbenzofuron-5-yl-methysulphonate] in conjunction with *Lolium perenne* L. to prevent *Poa annua* L. from invading a perennial ryegrass tee.

The study was initiated on the 5th tee Amherst Gold Club, Amherst, Massachusetts. Glyphosate was applied on the tee August 20, 1980 at a rate of 2.52 kg/ha to eradicate any existing grasses or weeds. One week later the tee was tilled, graded, and seeded with Manhattan perennial ryegrass at a rate of 384 kg/ha (Table 9). An area 7.2 m by 18.6 m was squared off on the tee and divided into 3 replications. Each replication contained 12 plots measuring 1.2 m by 3.1 m which received the same treatments as Experiment 1. Pre-emergence ethofumesate treatments were applied after seeding in August of 1980 (Table 10). The 5th tee received the same overseeding and herbicide treatments as the 9th tee from thereafter (Tables 9 and 10). Cultural practices, except for some fungicide treatments (Tables 14 and 16), data collection, and data analysis procedures were identical to those carried out in field Experiment 1 on the 9th tee.

Results. Untreated turfgrass had mean scores of 4.6 and 4.4 in 1981 and 1982 respectively (Table 12). Ratings of ethofumesate treated plots were significantly greater than untreated plots. Most treated replications had mean values in the range of 7.1-8.7. As in field Experiment 1 on the 9th tee, turfgrass treated with both the pre-emergence and post-emergence treatments rates of 0.84, 1.68 kg/ha and 1.12, 1.12 kg/ha had the greatest scores (Table 12). Although turf plots that received both the pre- and post-emergence treatments resulted in the highest stand composition estimates, they were not significantly greater than many of the pre-emergence, or the post-emergence treatments (Table 12).

Differences were not noted between 1981 pre-emergence treatments scores graphed over time (Figure 20). A small overall decline in ratings was noted through week 19 (last week of September) at which time the trend was reversed. The untreated control demonstrated a larger decline over the summer season than did the ethofumesate treated grass. Data taken at the end of May 1982 showed that the 0.84 kg/ha pre-emergence rate scored below the other rates (Figure 21). All the pre-emergence treated turfgrass plots had a rating between 7 and 8 at the end of August (week 14). Untreated control had a value increase from about 3 to 5 over the same period of time.

Post-emergence treatment scores graphed over time for 1981 and 1982 did not differ much from pre-emergence estimates. Scores for all rates tested followed the same trends in 1981 (Figure 22). The

TABLE 12

TREATMENT TIME, ETHOFUMESATE RATES, AND MEAN SCORE
EXPERIMENT 2 - 1981 AND 1982.

Treatment Time	Ethofumesate Rates kg/ha	Mean Score* 1981	Mean Score* 1982
Pre-emergence	0.84	7.1b[++]	6.3b
Pre-emergence	1.12	7.7bc	7.1b
Pre-emergence	1.68	7.8bc	8.0c
Post-emergence	0.84	7.7bc	8.0c
Post-emergence	1.12	7.5bc	7.1b
Post-emergence	1.68	7.7bc	8.0c
Pre + Post emergence	0.84 + 1.68	8.1c	8.7c
Pre + Post emergence	1.12 + 1.12	8.1c	8.6c
Pre + Post emergence	1.68 + 0.84	7.6a	8.5c
Untreated	0.00	4.6a	4.4a

*Scoring Scale = 1.0 → 5.0 → 9.0

Score	=	% Stand Composition
1.0	=	100% Annual bluegrass
5.0	=	50% Annual bluegrass, 50% Ryegrass
9.0	=	100% Ryegrass

[++]Values within columns followed by same letter are not significantly different at the 5% level.

Fig. 20. Mean Score Over Time of Turfgrass Treated with Pre-emergence Ethofumesate Application and Control, Experiment 2 - 1981.

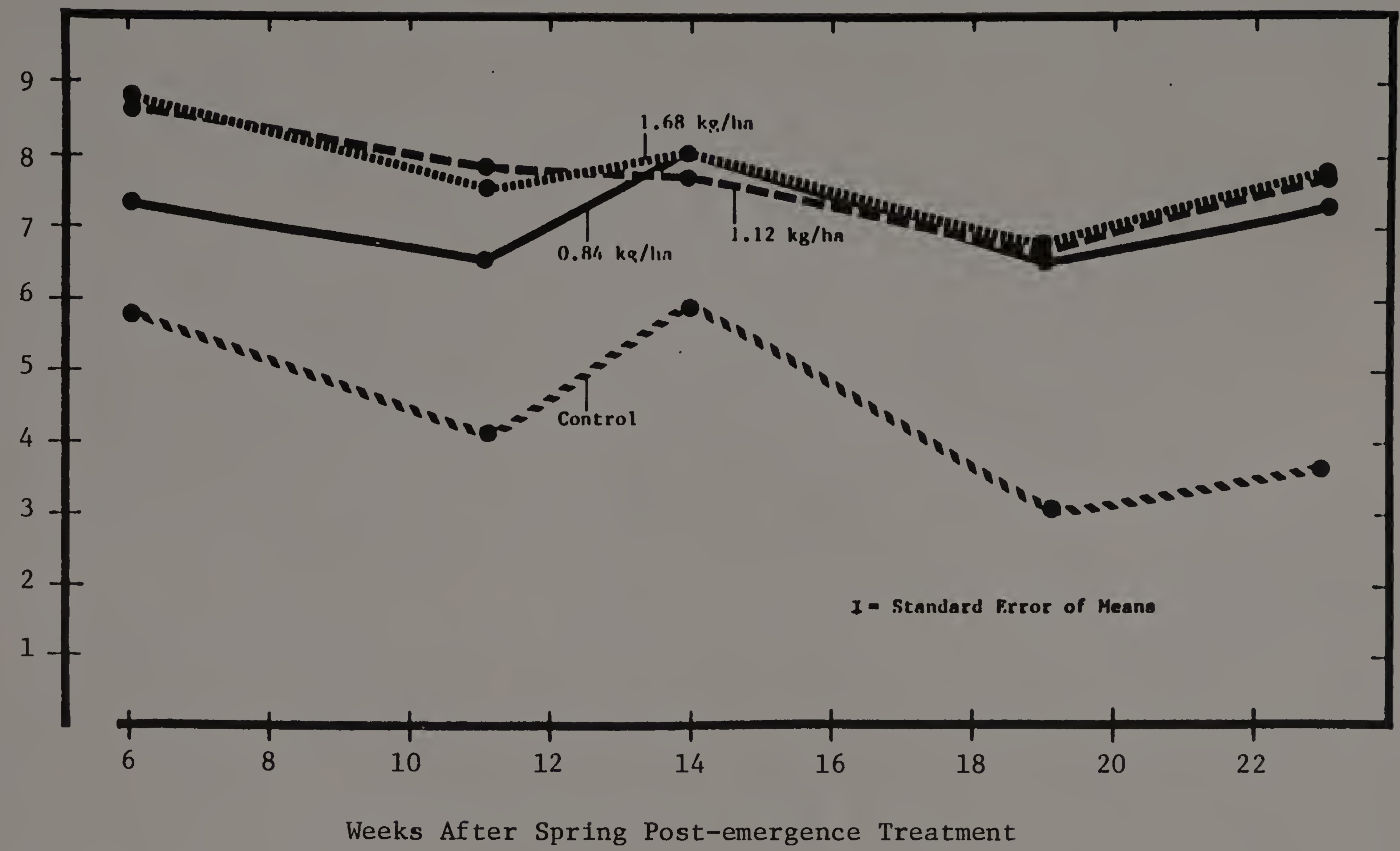


Fig. 21. Mean Score Over Time of Turfgrass Treated with Pre-emergence Ethofumesate Applications and Control, Experiment 2 - 1982.

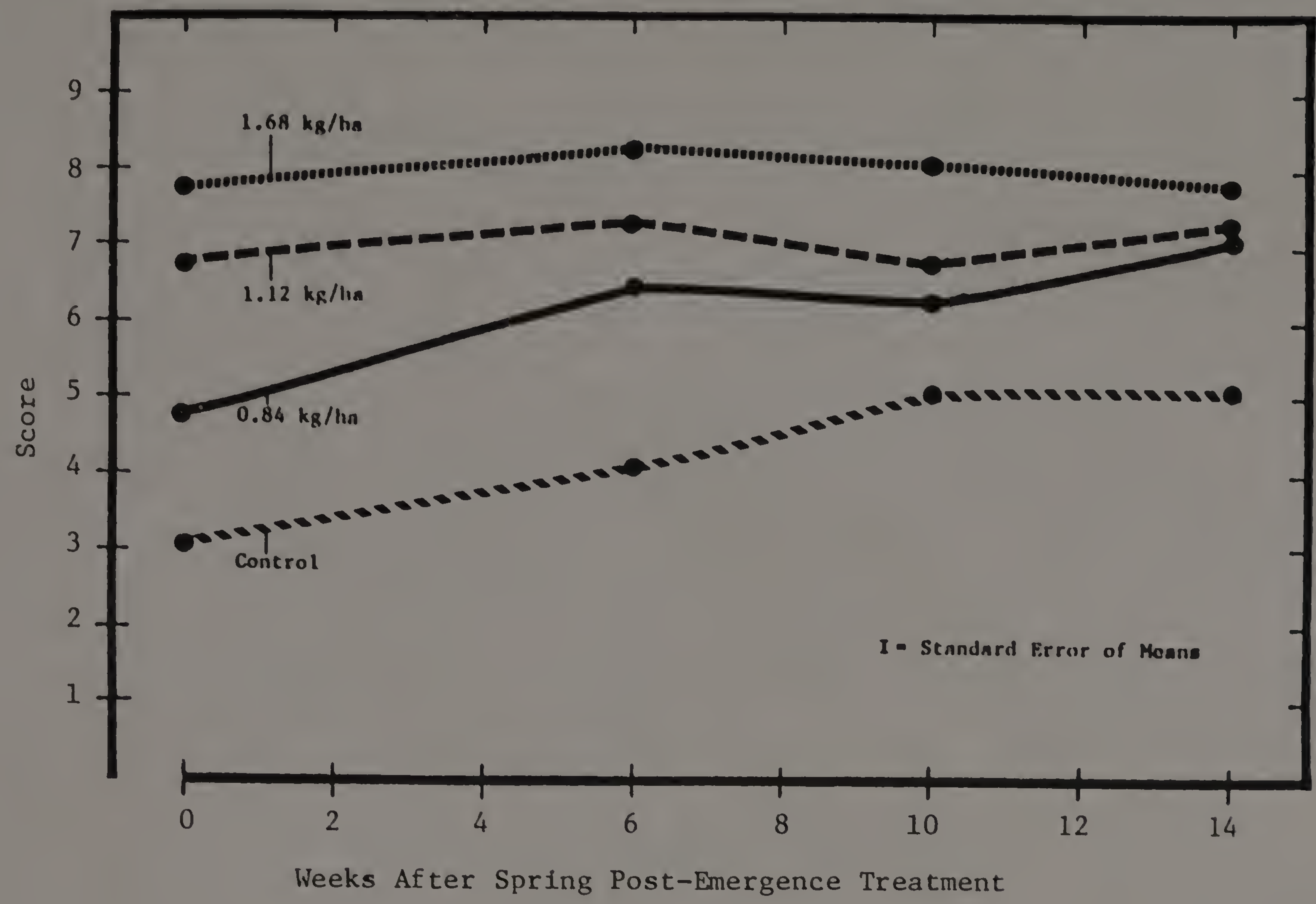
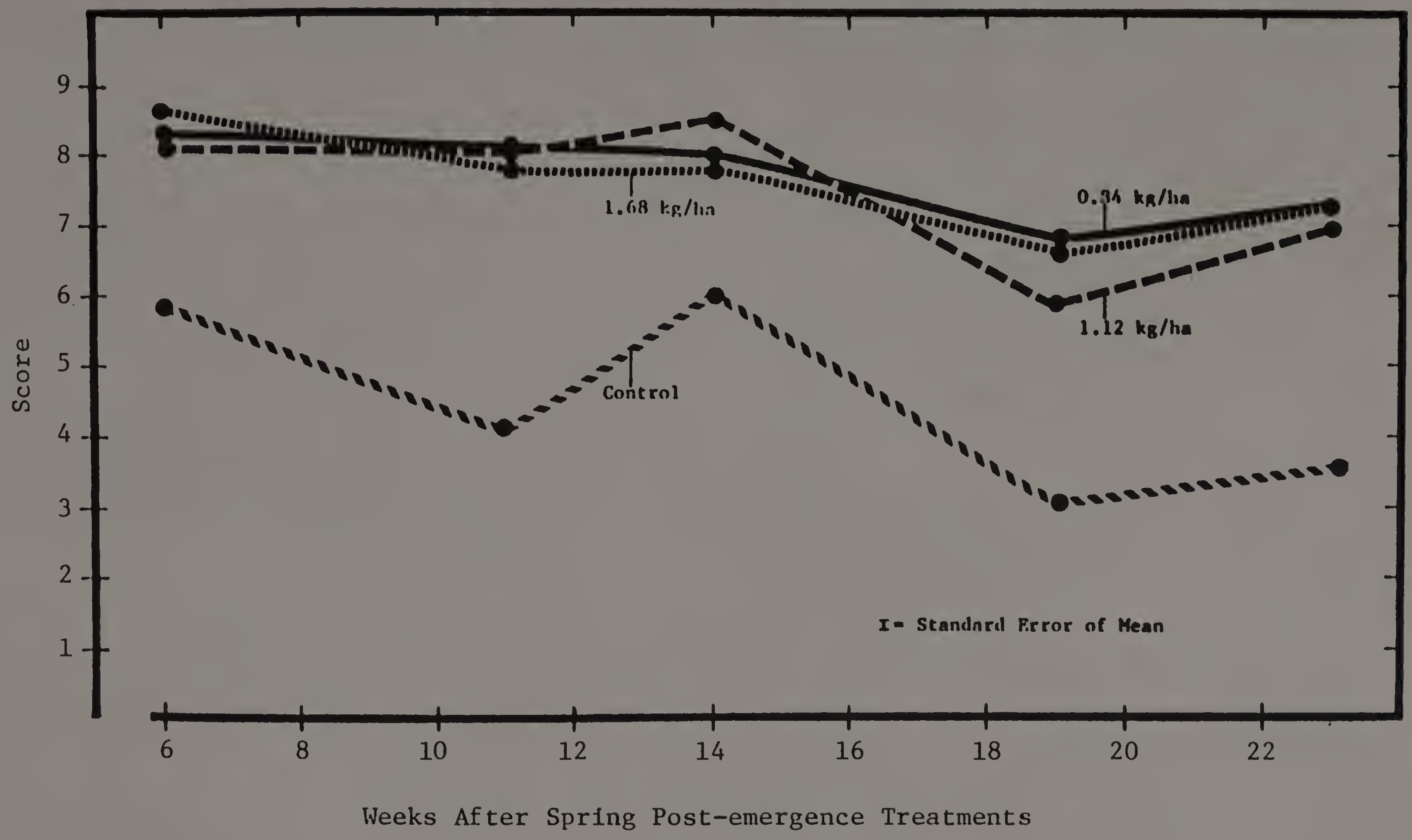


Fig. 22. Mean Score Over Time of Turfgrass Treated with Post-emergence Ethofumesate Applications and Control, Experiment 2 - 1981.



1982 data for the 1.12 kg/ha treatment averaged one unit below the 0.84 and 1.68 kg/ha rates (Figure 23). Untreated control plots demonstrated increased ratings until the end of July and then remained constant through August in 1982.

Difference in scores between grass treated with both pre-emergence and post-emergence treatments on the 5th tee were not evident in 1981 and 1982 (Figures 24 and 25).

Experiment 3: Conversion of a Poa annua L. Infested Fairway to Lolium perenne L. with Overseeding and Ethofumesate Treatments

Methods and materials. The objective of the study was to investigate the use of ethofumesate [(+-)2-ethoxy-2,3-dihydro-3,3-dimethylbenzo-furon-5-yl-methysulphonate] treatments in conjunction with a *Lolium perenne* L. overseeding program to transform an undesirable golf course fairway turfgrass that was predominatly *Poa annua* L. to a stand that contained desirable turfgrasses. It was also the objective of the experiment to achieve this result without removing the fairway from play.

The study was initiated on the 9th fairway at Amherst Golf Club, Amherst, Massachusetts at the end of August 1980. An area 15.0 m by 41.1 m with 3 replications containing 10 plots that measured 1.5 m by 13.7 m were laid out in a completely randomized block design. Overseeding with Manhattan perennial ryegrass on the fairway was carried out, with a slice seeder twice a year at a rate

Fig. 23. Mean Scores Over Time of Turfgrass Treated with Post-emergence Ethofumesate Applications and Control, Experiment 2 - 1982.

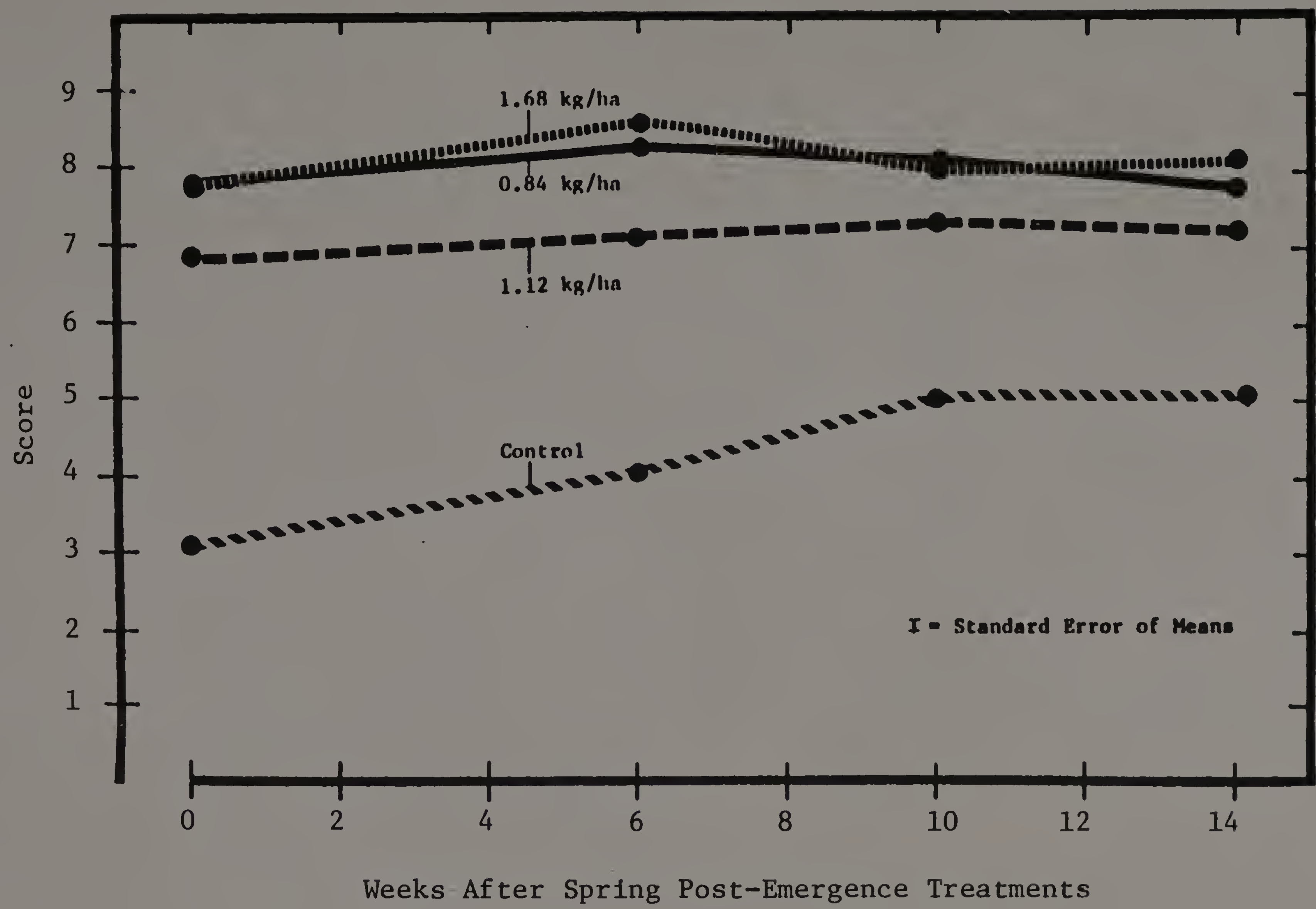


Fig. 24. Mean Score Over Time of Turfgrass Treated with Both Pre- and Post-Emergence Ethofumesate Applications and Control, Experiment 2 - 1981.

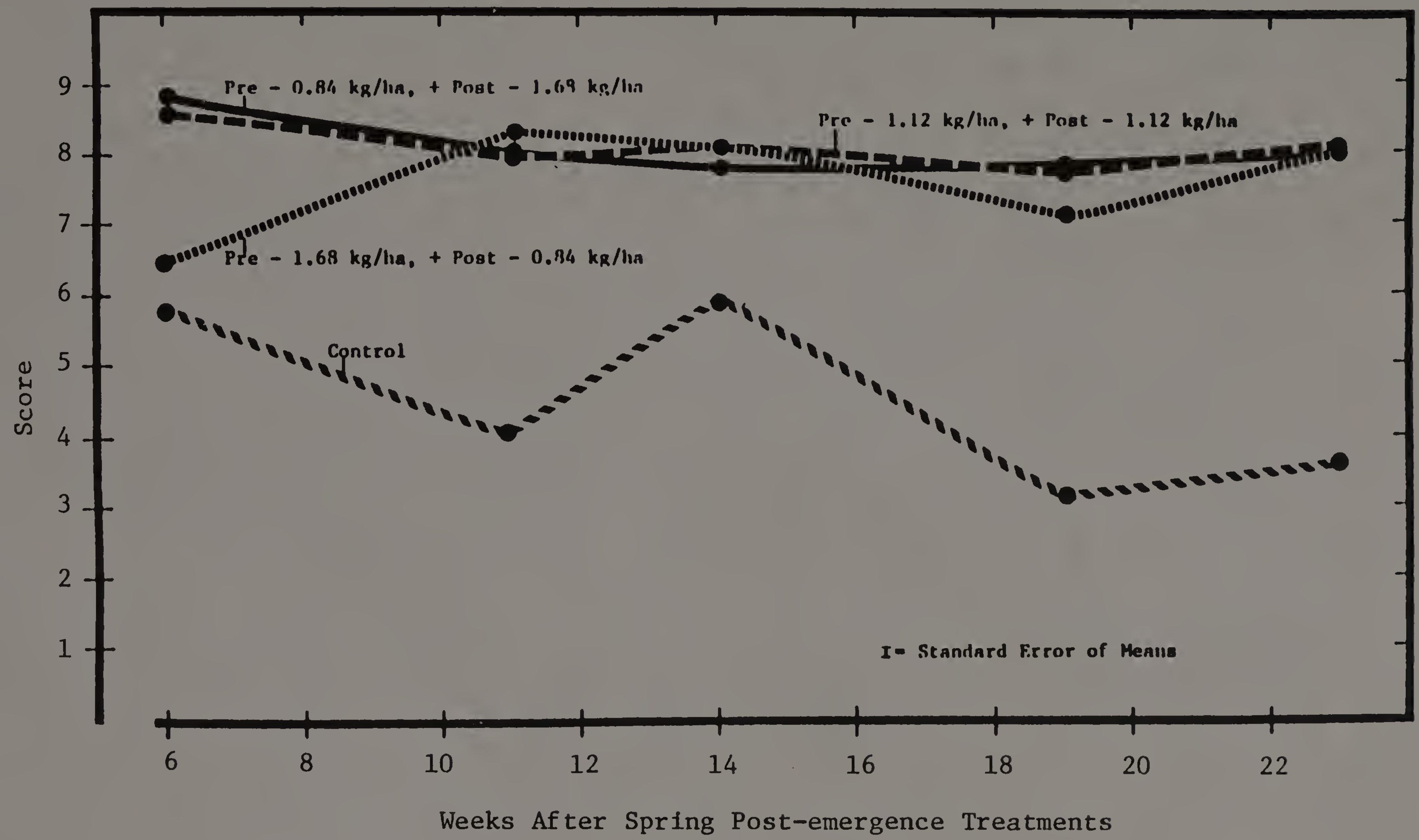
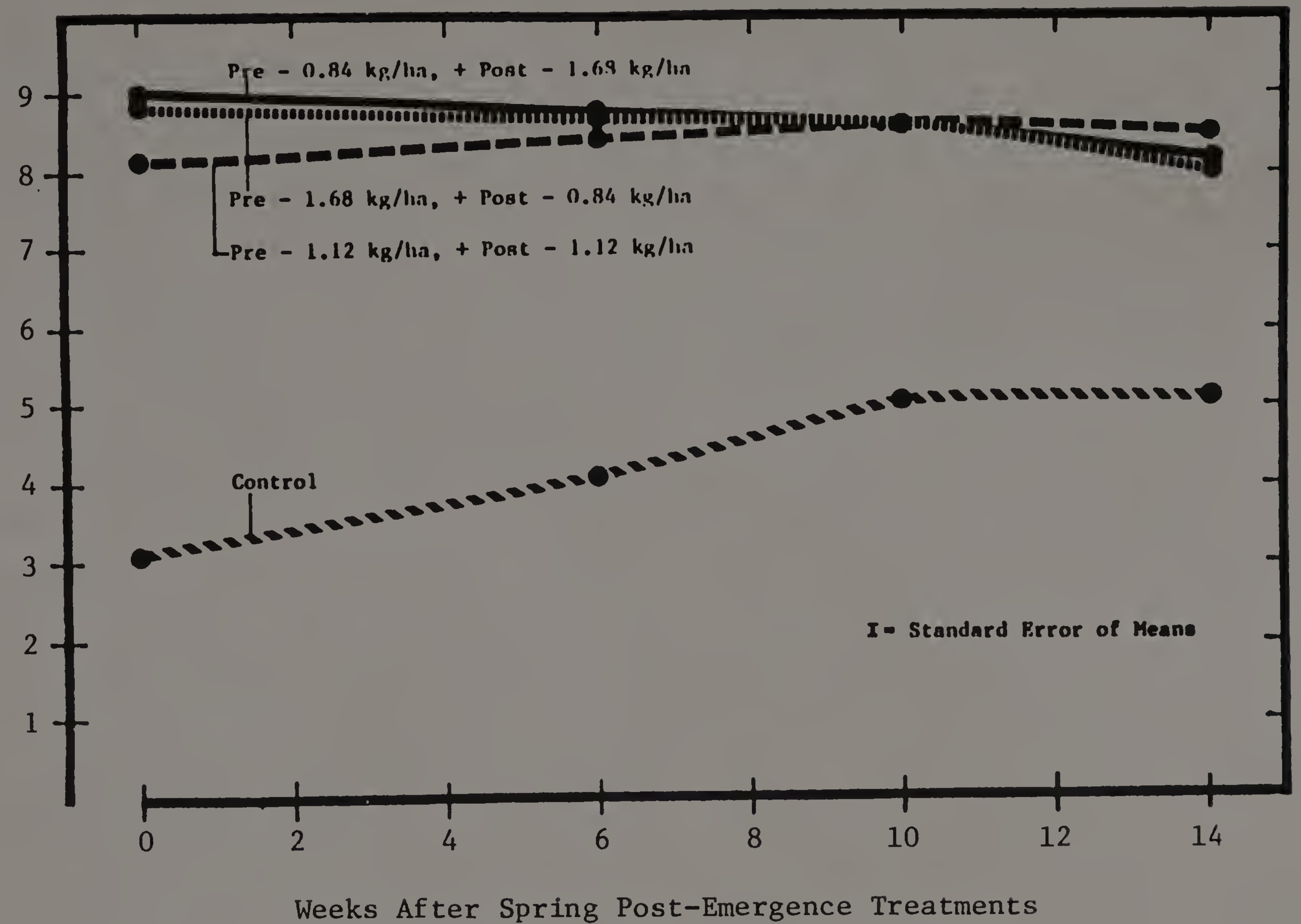


Fig. 25. Mean Scores Over Time of Turfgrass Treated with both Pre- and Post-emergence Ethofumesate Applications and Control, Experiment 2 - 1982.



of 195 kg/ha, prior to pre-emergence chemical treatments. The fairway was mowed after seeding to cut organic material left on the turf surface and settle it into the turf. Pre-emergence treatments were then applied. Pre-emergence, post-emergence, and both pre- and post-emergence treatments were applied to the turfgrass at three rates identical to treatments applied in field Experiments 1 and 2 (Table 10).

Three applications of nitrogen were made in 1980 totaling 146 kg/ha, and three 1981 applications totaled 134 kg/ha (Table 17). Nitrogen applications were not made in 1982. One pesticide application of Dursban was made in August 1981 to control Japanese beetles. The fairway was maintained at a cutting height of 1.9 cm until mid June when it was raised to 2.5 cm. In mid August the 1.9 cm cutting height was resumed. Data collection and analysis procedures were similar to ones used in field Experiments 1 and 2.

Results. All treatment mean scores except for grass treated with 0.84 kg/ha of ethofumesate applied as a pre-emergence treatment were significantly greater than the untreated control in 1981 (Table 13). Values for turfgrass sprayed with pre-emergence treatments were 3.4, 3.6, and 3.9 for the 0.84, 1.12, and 1.68 kg/ha rates respectively in 1981. Untreated control plots had a mean rating of 2.2. Scores for the post-emergence treated grass at the same rates were 4.2, 4.4, and 5.8 in 1981. The 5.8 stand composition estimate for the 1.68 kg/ha post-emergence treatment plots was significantly greater than values obtained from turf treated with the 3 pre-emergence

TABLE 13

TREATMENT TIME, ETHOFUMESATE RATES, AND MEAN SCORE, EXPERIMENT 3 - 1981 AND 1982.

Treatment Time	Ethofumesate Rates kg/ha	Mean Score* 1981	Mean Score* 1982
Pre-emergence	0.84	3.4ab	6.0c
Pre-emergence	1.12	3.6b	6.4cd
Pre-emergence	1.68	3.9b	6.9de
Post-emergence	0.84	4.2b	5.0b
Post-emergence	1.12	4.4bc	6.9de
Post-emergence	1.68	5.8cd	7.4ef
Pre + Post emergence	0.84 + 1.68	6.2d	8.0fg
Pre + Post emergence	1.12 + 1.12	6.5d	8.2g
Pre + Post emergence	1.68 + 0.84	5.7d	7.4ef
Untreated	0.00	2.2a	2.9a

*Scoring Scale = 1.0 → 5.0 → 9.0

Score	=	% Stand Composition
1.0	=	100% Annual bluegrass
5.0	=	50% Annual bluegrass, 50% Desirable Turfgrasses
9.0	=	100% Desirable Turfgrasses

++Values within columns followed by same letter are not significantly different at the 5% level.

treatments and the lowest post-emergence applications. The 1.68 kg/ha post-emergence treatment mean score was not significantly different from values obtained from the turf treated with both the pre-emergence and post-emergence applications.

Grasses sprayed with ethofumesate treated with both pre-emergence and post-emergence treatments, at rates of 0.84 and 1.68 kg/ha and 1.12 and 1.12 kg/ha, had the highest stand composition estimates in 1981 on the 9th fairway. In 1981 they had mean scores of 6.2 and 6.5 respectively (Table 13).

Mean scores for treated turf on the 9th fairway in 1982 were all significantly greater than the untreated grass (Table 13). The turf sprayed with both pre- and post-emergence treatments, at rates of 1.12 and 1.12 kg/ha, yielded significantly greater scores than all other treatments. Plots treated with both pre- and post-emergence treatments, at rates of 0.84 kg/ha and 1.68 kg/ha, had a stand composition estimate that was significantly greater than all pre-emergence treatments and most post-emergence treatments (Table 13).

Pre-emergence treatment plot scores for 1981 decreased slightly until the end of summer when stand composition estimates increased dramatically (Figure 26). The 1982 scores remained the same through the season at levels attained in 1981 (Figure 27). Ratings determined in 1982 for turfgrass treated with pre-emergence applications averaged between 6.0 and 7.0. Results for post-emergence treatments followed the same trends in 1981 as did pre-emergence treatments

Fig. 26. Mean Scores Over Time of Turfgrass Treated with Pre-emergence Ethofumesate Applications and Control, Experiment 3 - 1981.

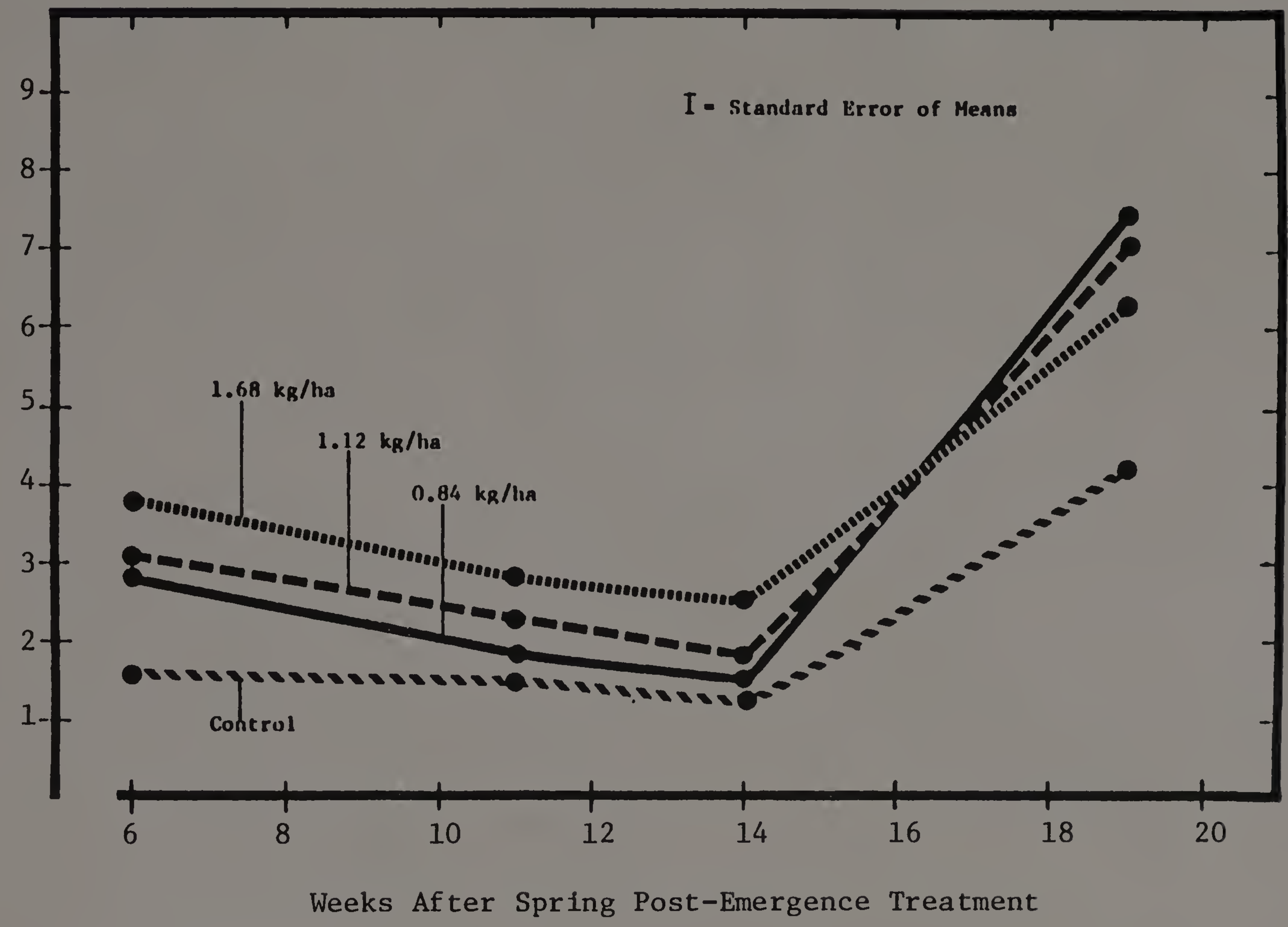
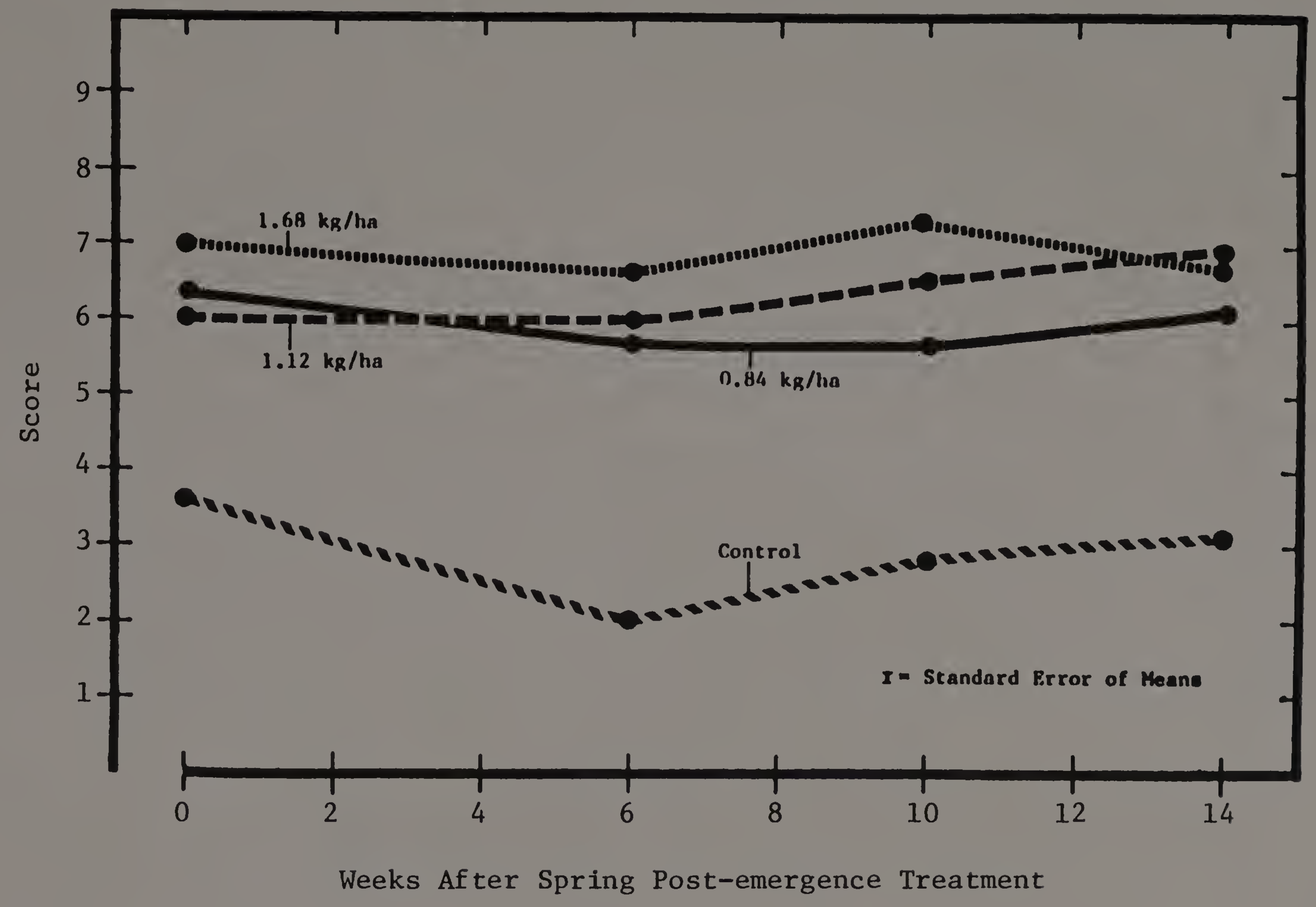


Fig. 27. Mean Score Over Time of Turfgrass Treated with Pre-emergence Ethofumesate Applications and Control, Experiment 3 - 1982.



(Figure 28). The 1982 scores were constant throughout the season, although differences between treatment rates were evident (Figure 29).

Stand composition estimates obtained in 1981 of turf treated with both pre-emergence and post-emergence ethofumesate applications followed the same pattern as the single pre-emergence or post-emergence treatments. Scores of these treatments declined until the end of the summer at which point they increased (Figure 30). High ratings attained in 1981 were maintained in 1982 until about week 10, the end of July, at which time a slight decline was noted (Figure 31).

Ridges and swales were present on the 9th fairway. It was noted swales within treatment plots often had stand compositions of close to 100% annual bluegrass. These areas were unrepresentative of the rest of the plot. Ridges on the fairway study were often scalped by mowers. Scalped areas often had noticeably greater numbers of young annual bluegrass plants than non scalped areas within the same plot.

Discussion

Field Experiments 1-3 were designed to investigate the use of ethofumesate treatments in conjunction with a *Lolium perenne* L. overseeding program to control *Poa annua* L. infestations. All results of these experiments were expressed in mean scores ranging from

Fig. 28. Mean Score Over Time of Turfgrass Treated with Post-emergence Ethofumesate Applications and Control, Experiment 3 - 1981.

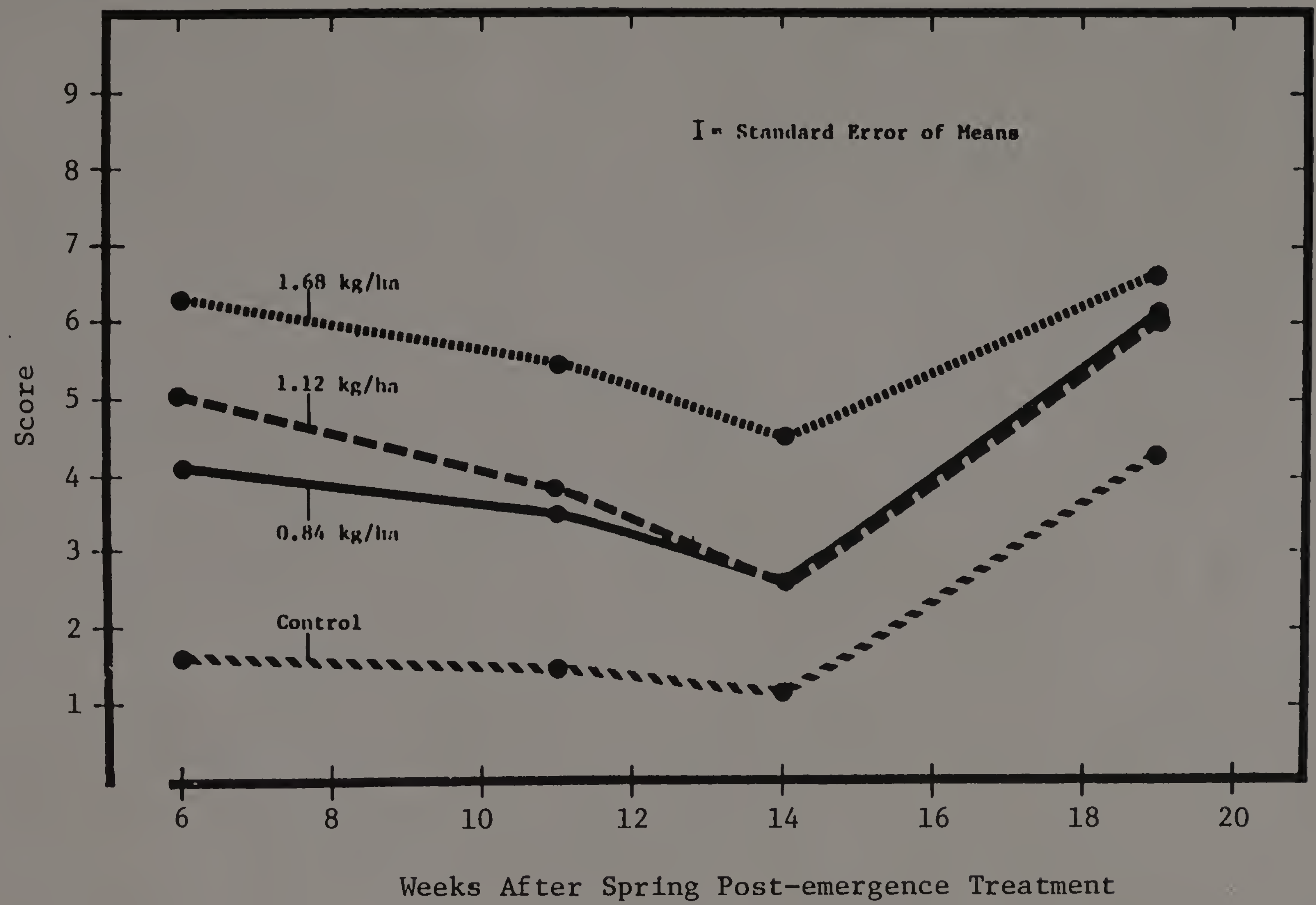


Fig. 29. Mean Scores Over Time of Turfgrass Treated with Post-emergence Ethofumesate Applications and Control, Experiment 3 - 1982.

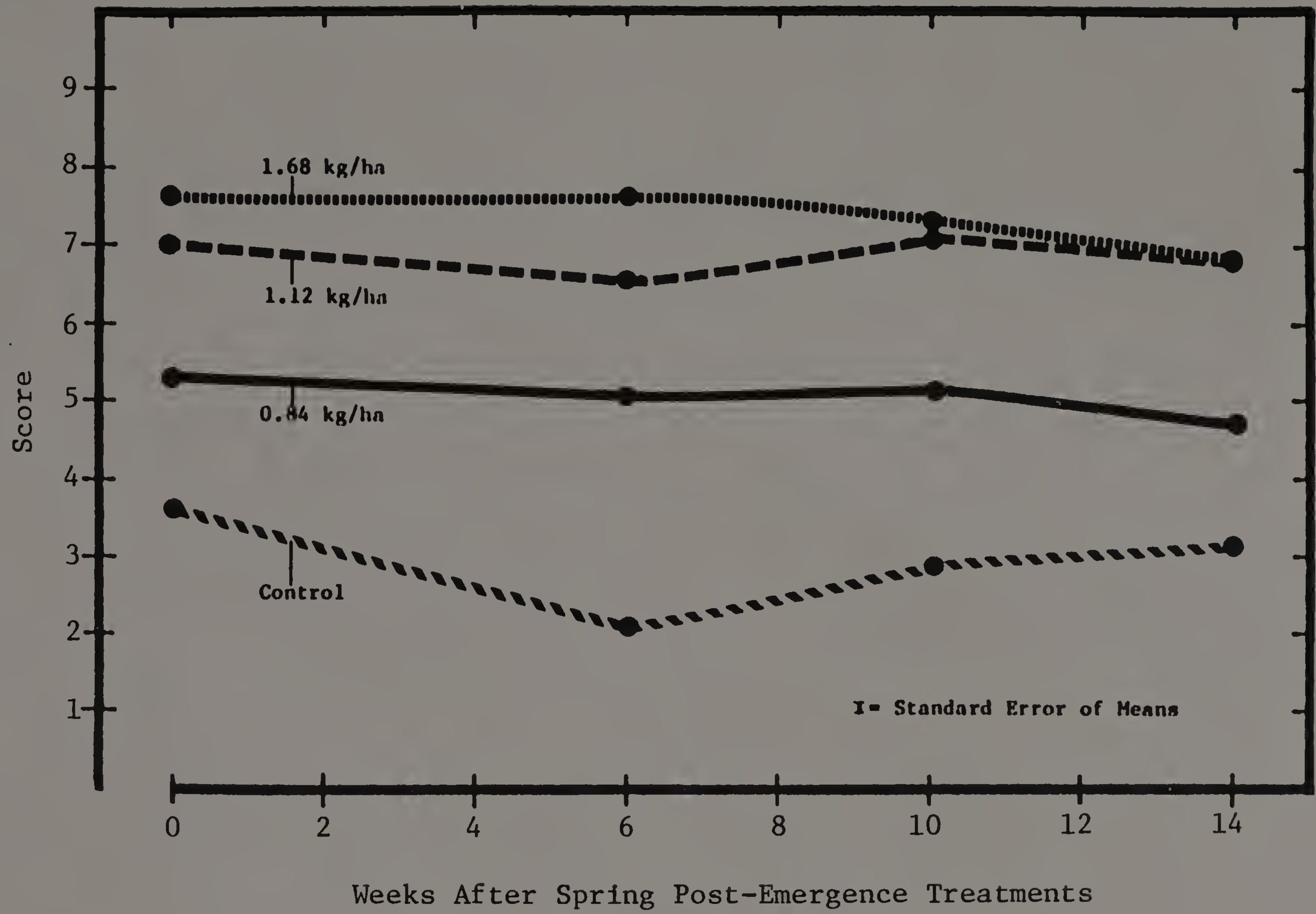


Fig. 30. Mean Score Over Time of Turfgrass Treated with Both Pre- and Post-emergence Ethofumesate Applications and Control, Experiment 3 - 1981.

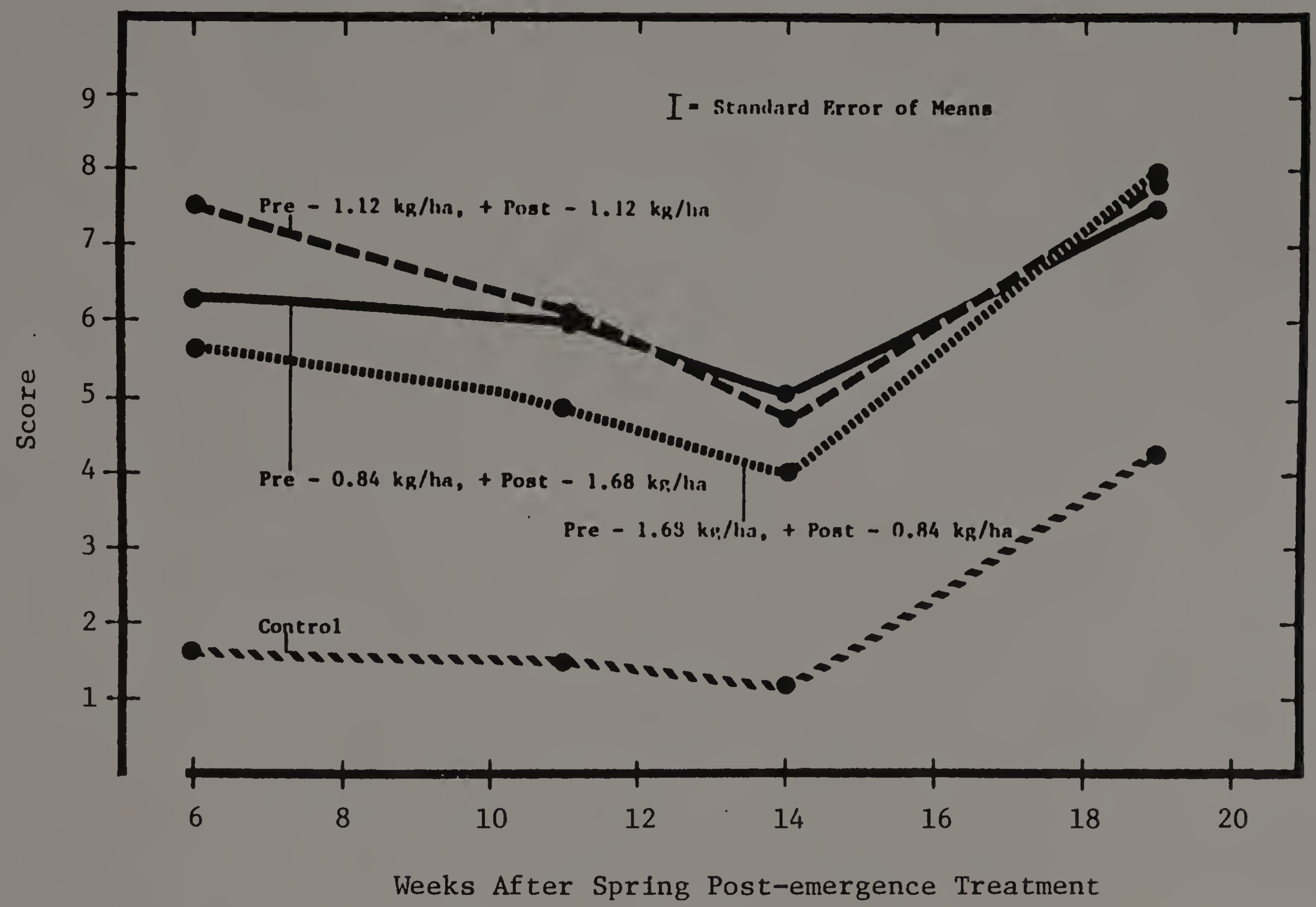
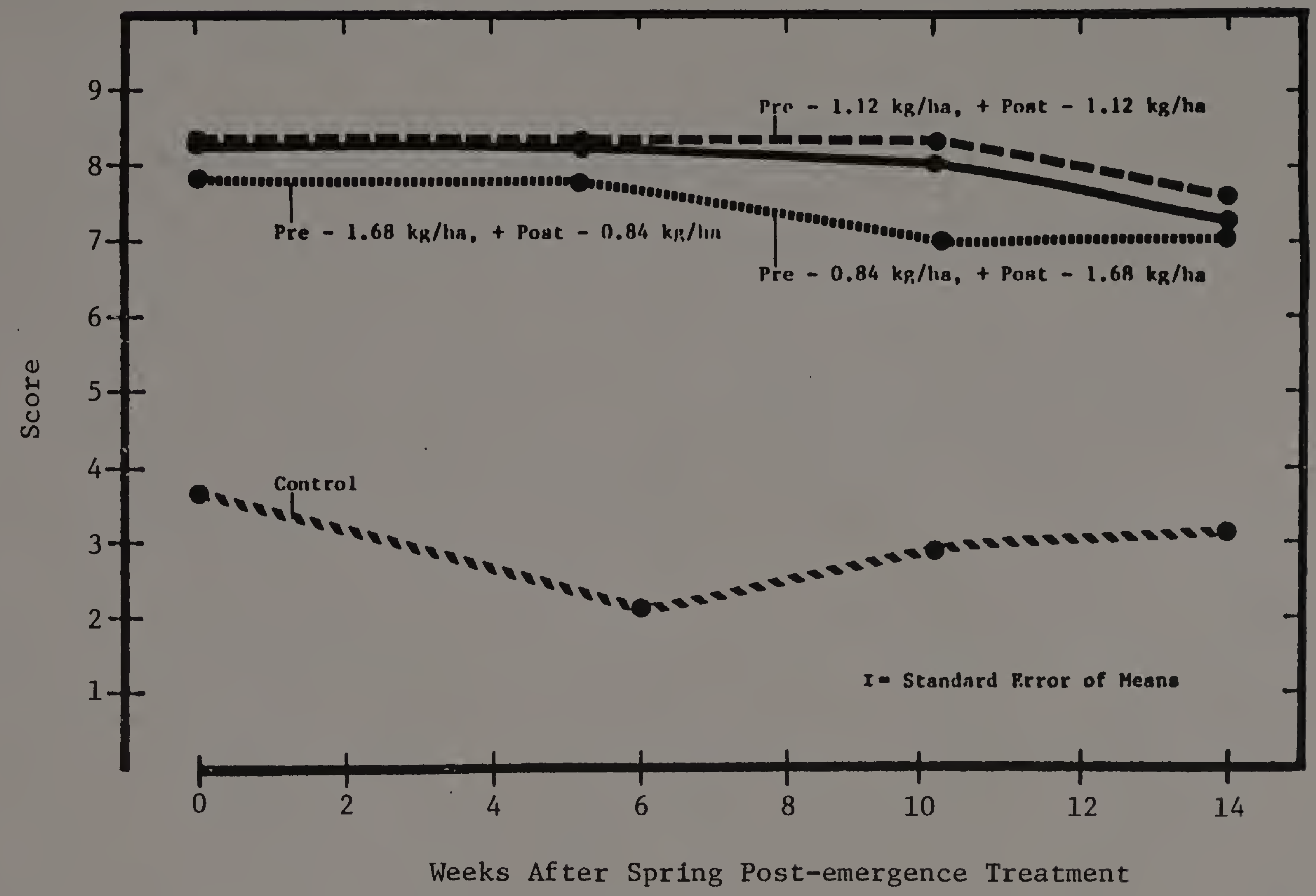


Fig. 31. Mean Scores Over Time of Turfgrass Treated with Both Pre- and Post-emergence Ethofumesate Applications and Control, Experiment 3 - 1982.



1-9. Since the objective of these experiments was to eliminate annual bluegrass a score of 9.0 or close to 9.0 was highly desirable. To obtain the scores visual estimates of the stand composition were made. The composition estimates were of the percent annual bluegrass shoots and percent perennial ryegrass shoots in the turf canopy.

Differences in annual bluegrass control in turf between both the pre-emergence and post-emergence treatment times, and the treatment rates did exist. Results over time indicated the overseeding program combined with ethofumesate treatments increased the percent stand composition of perennial ryegrass in Experiments 1 and 3. Experiment 2 demonstrated that ethofumesate treatments along with the ryegrass overseeding program prevented invasion of annual bluegrass in a ryegrass tee. Data from all three experiments indicate the most effective treatments were ones which contained both pre-emergence and post-emergence treatments.

As rates of ethofumesate increased from 0.84-1.68 kg/ha the control of annual bluegrass increased. This trend was evident in the 1981 and 1982 data for both pre-emergence and post-emergence treated turf on the 9th tee and 9th fairway (Tables 11 and 13). Scores for pre-emergence treatment rates of 0.84, 1.12, and 1.68 kg/ha on the 9th tee in 1982 were 4.3, 4.6, and 6.1 respectively which is equal to approximately 41%, 45%, and 64% ryegrass in the stands. The control had a stand composition of about 27% ryegrass in 1982. Post-emergence treated turfgrass on the 9th fairway had scores of 5.0, 6.9, and 7.4 for the 0.84, 1.12, and 1.68 kg/ha rates. These results correspond to approximately 50%, 74%, and 80% ryegrass stands. Increase in control with increased rates was probably related to a longer period of herbicide activity. Schweizer (55) found that the half life of ethofumesate in the soil was independent of the rate applied. The greater rates could have insured that the level of ethofumesate needed for control was above the threshold level required to inhibit annual bluegrass germination for a longer period of time.

Results from the 5th tee enforce rate trends observed in Experiments 1 and 3. Differences in results between grass sprayed with ethofumesate pre-emergence rates on the 5th tee were evident in 1982 (Table 12). More annual bluegrass was observed on the plots of the lower rates. Rates of 0.84, 1.12, and 1.68 kg/ha had mean scores of 6.3, 7.1, and 8.0 in 1982. These ratings correspond to about 66%, 76%, and 88% ryegrass in the stand. The untreated control plot had a mean score of 4.2 or about 43% ryegrass in 1982. Since the 5th tee was renovated to ryegrass at the beginning of the study it would be expected that the stand composition estimates would be greater than the other studies. Comparing control plots to results of pre-emergence treated plots it is evident that ethofumesate prevented the ingress of annual bluegrass and the greater rates were more effective than lower rates tested. A rate effect was not evident in the post-emergence treatments on the 5th tee.

Results differed for identical rates applied at different times.

Turfgrass treated with post-emergence applications resulted in greater scores than pre-emergence treated plots at the same rates during both seasons in Experiments 1 and 3 (Tables 11 and 13). Percent ryegrass in the turf stand on the 9th tee for the 0.84, 1.12, and 1.68 kg/ha pre-emergence treatment rates were estimated to be 20%, 26%, and 43% ryegrass in 1981. Post-emergence treatments at the same rates were estimated to be 48%, 59%, and 61% ryegrass in 1981. Results indicated late May and late September treatments (post-emergence) provided greater control. This was probably because these applications were closer to the time of seed germination or soon after emergence of the annual bluegrass than that of the pre-emergence treatments. Ethofumesate has to be present at the time of germination for successful control because it has been shown the primary mode of uptake of the herbicide was by emerging shoots of seedlings or new shoots of mature plants (44). The results seem to indicate that the pre-emergence treatments were applied too early to achieve as much control as the post-emergence time of application during the years tested. It was assumed that some degredation of the pre-emergence treatment took place by the time the majority of the annual bluegrass seeds began to germinate. The lower concentration of ethofumesate at the time of germination allowed more plants to survive and grow. It should be remembered that germination of annual bluegrass is environmentally dependent and could occur at any time if conditions are proper.

The results from the 5th tee support Experiments 1 and 3. The mean score resulting from the 0.84 kg/ha pre-emergence treatment was 4.8 or about 48% ryegrass in May of 1982 (Figure 21). It was conjectured that the low rate applied in August 1981 did not provide adequate control later in the fall. Annual bluegrass plants that were able to establish themselves grew and caused a depression in the score for the ethofumesate pre-emergence 0.84 kg/ha treated grass in the spring of 1982. The turf sprayed with the 0.84 kg/ha post-emergence treatment, applied in late September 1981, had a score of 6.8 or about 75% ryegrass in May of 1982 (Figure 23) indicating the later treatment time provided more control of annual bluegrass.

Ethofumesate pre-emergence treatments followed by post-emergence treatments yielded significantly greater control of annual bluegrass than single applications. Turfgrass treated with both pre- and post-emergence treatment rates of 0.84, 1.68 kg/ha and other turf treated with the 1.12, 1.12 kg/ha applications yielded the greatest control of annual bluegrass in Experiments 1, 2, and 3. Both of these treatments had scores of 8.1 or about 90% ryegrass in 1982 on the 9th tee (Table 11). . Results for the same treatments were 8.0 and 8.2 on the 9th fairway in 1982 (Table 13). Grass on the 5th tee that was treated with both pre- and post-emergence applications had stand composition estimates of 8.7 and 8.6 or about 85% ryegrass (Table 12).

More than one possible explanation for these results exists. Pre- and post-emergence treatments applied in late April and late mean score resulting from the 0.84 kg/ha pre-emergence treatment was 4.8 or about 48% ryegrass in May of 1982 (Figure 21). It was conjectured that the low rate applied in August 1981 did not provide adequate control later in the fall. Annual bluegrass plants that were able to establish themselves grew and caused a depression in the score for the ethofumesate pre-emergence 0.84 kg/ha treated grass in the spring of 1982. The turf sprayed with the 0.84 kg/ha post-emergence treatment, applied in late September 1981, had a score of 6.8 or about 75% ryegrass in May of 1982 (Figure 23) indicating the later treatment time provided more control of annual bluegrass.

Ethofumesate pre-emergence treatments followed by post-emergence treatments yielded significantly greater control of annual bluegrass than single applications. Turfgrass treated with both pre- and post-emergence treatment rates of 0.84, 1.68 kg/ha and other turf treated with the 1.12, 1.12 kg/ha applications yielded the greatest control of annual bluegrass in Experiments 1, 2, and 3. Both of these treatments had scores of 8.1 or about 90% ryegrass in 1982 on the 9th tee (Table 11). . Results for the same treatments were 8.0 and 8.2 on the 9th fairway in 1982 (Table 13). Grass on the 5th tee that was treated with both pre- and post-emergence applications had stand composition estimates of 8.7 and 8.6 or about 85% ryegrass (Table 12).

More than one possible explanation for these results exists. Pre- and post-emergence treatments applied in late April and late in the fall of 1981. Increases in stand composition estimates of untreated and treated plots was attributed to overseeding with ryegrass at the time of herbicide applications. The greater score of the 1.68 kg/ha rate was attributed to more effective suppression of annual bluegrass germination and growth. A score decrease on pre-emergence plots was evident from October 1981 to May 1982 (Figures 14 and 15). It is conjectured that the decrease in values was because of growth of annual bluegrass that germinated late in the fall after the inhibitory effect of the herbicide had subsided. The 1982 ethofumesate pre-emergence data over time exhibits greater relative gain of the 2 lower herbicide rates in Experiment 1, but at the end of the season they were still below the 1.68 kg/ha rate (Figure 15).

Pre-emergence treated turf on the 9th fairway exhibited a large increase in scores during the fall of 1981 (Figure 26). Again, this result was attributed to the establishment of perennial ryegrass by overseeding, and the reduction of annual bluegrass germination by ethofumesate treatments. Score increases attained in 1981 on the 9th fairway were maintained by the overseeding and herbicide treatment program in 1982 (Figure 27). High scores were generally maintained by pre-emergence treatments on the ryegrass stand on the 5th tee during 1981 and 1982 (Figures 20 and 21). Ingress of annual bluegrass was evident in the untreated plots of this study, indicating that the pre-emergence treatments limited annual bluegrass germination.

Post-emergence treatment plot scores were greater than pre-emergence treatment results on the 9th tee and 9th fairway in 1981 (Figures 16 and 28), and to a lesser degree in 1982 (Figures 17 and 29). These values indicate greater control of annual bluegrass which demonstrates that the post-emergence application of ethofumesate was more effective during 1981 and 1982 than pre-emergence treatments. By the end of the 1982 season results were comparable over all post-emergence rates on the 9th tee (Figure 17). Turfgrass treated with the 0.84 kg/ha rate had a lower score compared to the higher post-emergence rates on the 9th fairway (Figure 29).

Turfgrass treated with both pre- and post-emergence applications at rates of 0.84 kg/ha followed by 1.68 kg/ha and other turf treated with 1.12 kg/ha followed by 1.12 kg/ha had scores greater than 7.5 in June of 1981 (Figure 18). These high scores increased slightly during 1981 and were over 8.0 during 1982 (Figure 19). A rating of 8.0 corresponds to a stand estimate of 88% ryegrass. These results indicate that after pre- and post-emergence treatments in the fall of 1980 and pre- and post-emergence treatments in the spring of 1981 most of the annual bluegrass was eliminated. Once control was achieved results remained constant throughout 1982 (Figures 19 and 20). There was no obvious explanation for the lower control in 1981 by pre- and post-emergence treatments that received the 1.68, 0.84 kg/ha rates compared to the other pre- and post-emergence treatments.

Obvious differences between single pre-emergence or post-emergence, and both pre- and post-emergence treatments on the 5th tee did not exist in 1981. This was attributed to the fact that the study was initiated on a renovated tee that was planted with ryegrass. Scores obtained during 1982 did exhibit differences between single and double application treatments. Over a longer period of time turf that received both pre- and post-emergence treatments allowed less germination of annual bluegrass than did the single treatments. Turf on the 9th fairway that was treated with both pre- and post-emergence applications also had the least amount of annual bluegrass.

It was noted that a swale present on the 9th tee and 9th fairway that ran through some treated plots had considerably more annual bluegrass than other areas within the plots. More than one hypothesis can be used to explain these results. One explanation is there was less microbial activity because of a presumed higher moisture content in the swale. The lower microbial activity could result in less decomposition of the organic matter. The organic matter could tie up more of the herbicide yielding less effective control. Another possible explanation is that the environment in the swale was more favorable to annual bluegrass growth. A combination of both factors could have contributed to the increased stand composition of annual bluegrass in the swale.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Competition Experiments

Data from competition experiments 1-4 suggest that annual bluegrass is a more successful competitor than the turf type perennial ryegrasses or Kentucky bluegrass cultivars. Results of Experiment 1 indicated that annual bluegrass tillered at a faster rate than the other species. Kentucky bluegrasses tillered faster than perennial ryegrass cultivars once rhizomes emerged. Rhizome production could make Kentucky bluegrasses more competitive against annual bluegrass than perennial ryegrasses in a stand maintained for more than a few months if the Kentucky bluegrass could be successfully established.

Results obtained from Experiment 1 at week 20 demonstrated that annual bluegrass grown against itself tillered the greatest and had the largest shoot dry weight. Kentucky bluegrasses tested generally tillered more and had larger shoot dry weights than perennial ryegrasses. Grasses grown in the center that tillered the most, such as annual bluegrass, generally reduced the tiller counts and mean shoot dry weight of the 4 surrounding plants. A few center grown cultivars that tillered poorly reduced the size of the 4 outside plants. It is possible that an alleopathic relationship between some of these grasses and annual bluegrass existed.

Experiment 2 enforce results of Experiment 1. Annual bluegrass grown in the center surrounded by 4 annual bluegrass plants tillered less than when surrounded by any of the 4 turfgrass plants of the cultivars grown. Four plants surrounding the center annual bluegrass plant with the largest tiller numbers limited annual bluegrass tiller counts more than 4 surrounding plants with a smaller tiller number. However, Norlea and Citation perennial ryegrasses were obvious exceptions.

Competition Experiments 3 and 4 tested seedlings of turfgrasses against tillers of annual bluegrass. Annual bluegrass seedlings were more competitive than the other grasses tested. Half of the perennial ryegrasses tested tillered as much or more than the Kentucky bluegrasses in these experiments. These results were attributed to the rapid germination and establishment of the ryegrass seeds compared to that of Kentucky bluegrass seeds. Results of these experiments indicated annual bluegrass was a more aggressive competitor when grown with other turfgrasses, but differences between grasses tested did exist.

Ethofumesate Toxicology

Ethofumesate ranging in rates from 0.42-6.72 kg/ha applied to Kentucky bluegrasses, creeping bentgrasses, and annual bluegrass grown in sand had a detrimental effect on growth. All rates of the herbicide applied significantly reduced tillering of all grasses compared to untreated replications. Mean shoot dry weights of treated turfgrasses were significantly different from untreated plants. Treated plants for most turfgrasses tested had smaller shoot dry weights than untreated grasses. Significant differences between root dry weights and root lengths of treated cultivars and untreated plants did exist. Trends of treatment effects of the chemical on root dry weights of Kentucky bluegrasses were not obvious. Root dry weights for untreated creeping bentgrass replications were less when compared to treatment rates 0.84 kg/ha and greater. There were no increasing or decreasing trends of root lengths over rates on Kentucky bluegrasses tested. Treated plants of creeping bentgrasses had longer roots than untreated controls.

Ethofumesate caused abnormal growth of the crown tissue of Kentucky bluegrass creeping bentgrasses, and annual bluegrass; rhizomes of Kentucky bluegrass; and stolon nodes of creeping bentgrasses.

Field Experiments

Resulting scores of field Experiments 1-3 graphed over time illustrate that overseeding sports turf with perennial ryegrass and applications of ethofumesate controlled annual bluegrass infestations. A more rapid increase in percent ryegrass in chemically treated plots versus untreated plots was observed when comparing results of field Experiments 1 and 3 over time. Experiment 2 control plots which were almost 100% ryegrass at the initiation of the study declined to more than 50% annual bluegrass in 2 years. This result indicated that chemical treatment was needed in addition to ryegrass overseeding to control annual bluegrass.

Two post-emergence applications annually provided greater control than two pre-emergence applications a year in Experiments 1 and 3. Increased treatment rates provided an increase in control of annual bluegrass. The highest of the 3 rates provided the greatest control of annual bluegrass for both the pre-emergence and post-emergence treatments in Experiments 1 and 3. A rate effect was also noted on pre-emergence treatments on field Experiment 2, but not on post-emergence plots. Combination pre- and post-emergence treatments (4 annual applications) provided the greatest control in all field tests.

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APPENDIX

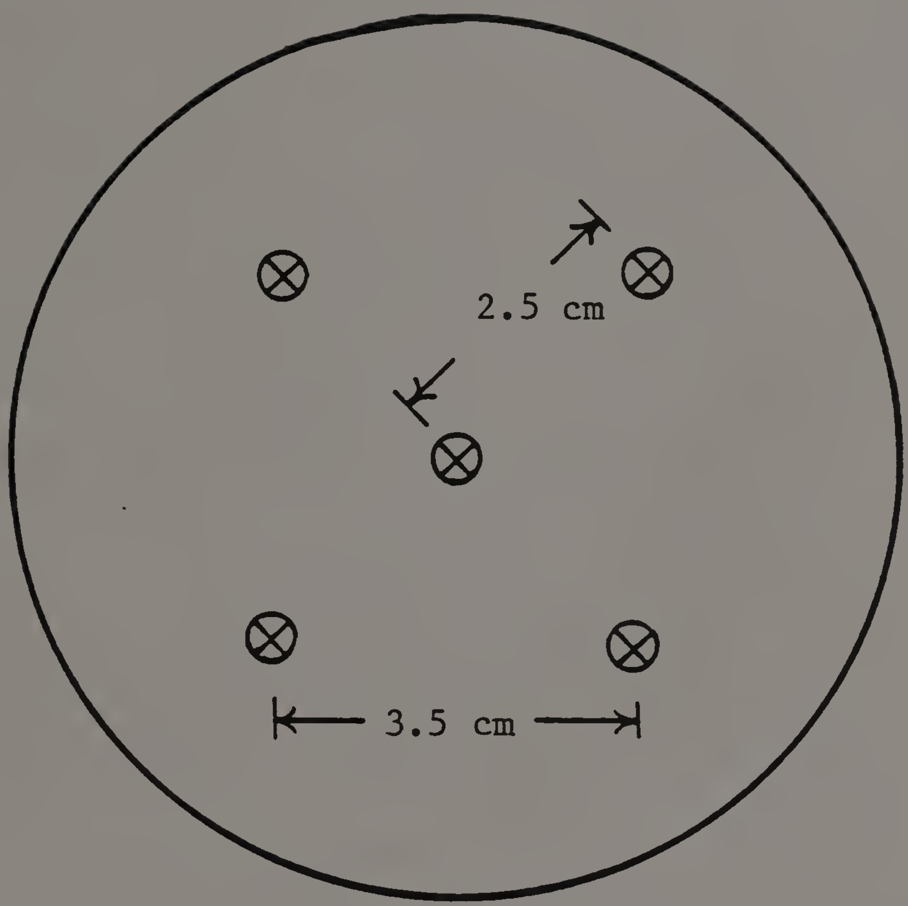

Fig. 32. Diagram of Template Used in Competition Experiments 1-4 to Insure Uniform Plant Spacings.

TABLE 14

DATE AND AMOUNT OF NITROGEN APPLIED TO FIELD EXPERIMENTS 1 AND 2 - 1980 AND 1981.

1980		1981	
Date	Nitrogen kg/ha	Date	Nitrogen kg/ha
4/20	36.6	4/29	48.8
6/04	24.4	5/27	9.2
7/01	9.2	6/12	9.2
7/29	6.1	6/23	6.1
8/22	9.2	7/8	6.1
9/15	24.4	8/6	9.2
11/20	36.6	8/20	12.2
		9/18	24.4
Total	146.5	Total	125.2

TABLE 15

DATE, PESTICIDE, AND AMOUNT OF FORMULATION APPLIED TO FIELD EXPERIMENT 1 - 1980 AND 1981.

1980			1981		
Date	Pesticide	Formulation Amount/Area	Date	Pesticide	Formulation Amount/Area
4/26	Betasan	152.1 l/ha	4/23	Betasan	152.7 l/ha
5/14	Chipco 26019	6.1 kg/ha	5/22	Daconil 2787	152.7 l/ha
5/23	Tri-Mec Bentgrass Formula	25.5 l/ha	6/3	Tri-Mec Bentgrass Formula	25.1 l/ha
6/6	Chipco 26019	6.1 kg/ha	6/10	Chipco 26019	6.1 kg/ha
7/8	Lesco Thiram	24.4 kg/ha	6/29	Lesco 4	18.3 kg/ha
7/24	Chipco 26019	6.1 kg/ha	7/10	Chipco 26019	6.1 kg/ha
8/23	Chipco 26019	6.1 kg/ha	8/13	Chipco 26019	6.1 kg/ha

TABLE 16

DATE, PESTICIDE, AND AMOUNT OF FORMULATION APPLIED TO FIELD EXPERIMENT 2 - 1980 AND 1981.

1980			1981		
Date	Pesticide	Formulation Amount/Area	Date	Pesticide	Formulation Amount/Area
4/26	Betason	152.7 l/ha	4/23	Betasan	152.7 l/ha
5/14	Chipco 26019	6.1 kg/ha	5/22	Daconil 2787	152.7 l/ha
5/23	Tri-Mec Bentgrass Form	25.5 l/ha	6/3	Tri-Mec Bentgrass Form	25.5 l/ha
6/6	Chipco 26019	6.1 kg/ha	6/10	Chipco 26019	6.1 kg/ha
7/24	Chipco 26019	6.1 kg/ha	6/29	Lesco 4	18.3 kg/ha
8/23	Chipco 26019	6.1 kg/ha	7/5	Tersan sp	21.3 kg/ha
			7/14	Tersan sp	21.3 kg/ha
			8/3	Chipco 26019	6.1 kg/ha

TABLE 17

DATE AND AMOUNT OF NITROGEN APPLIED TO FIELD EXPERIMENT 3 - 1980 AND 1981.

1980		1981	
Date	Amount kg/ha	Date	Amount kg/ha
6/15	61.0	6/8	36.6
9/10	36.6	9/7	48.8
11/15	48.8	11/22	48.8
Total	146.4	Total	134.2